CHAPTER 4

Experiment and Result

This chapter presents simulation result with PSIM program, MATLAB m-file program and testing electrical equipment immunity voltage sag inverter 3-phase 4-wire 4-leg hardware and carrier-based pulse width modulation and sag algorithm in international standard IEC61000-4-11 and SEMI F47.

s

4.1 The result of simulation of voltage source inverter

The 3-phase 4-wire voltage source inverter topology has designed in chapter 3 in this chapter will be implementation and experiment in PSIM Software with the DLL block written in c programing language to calculate min and max value of voltage reference and then calculate value to zero sequence signal.

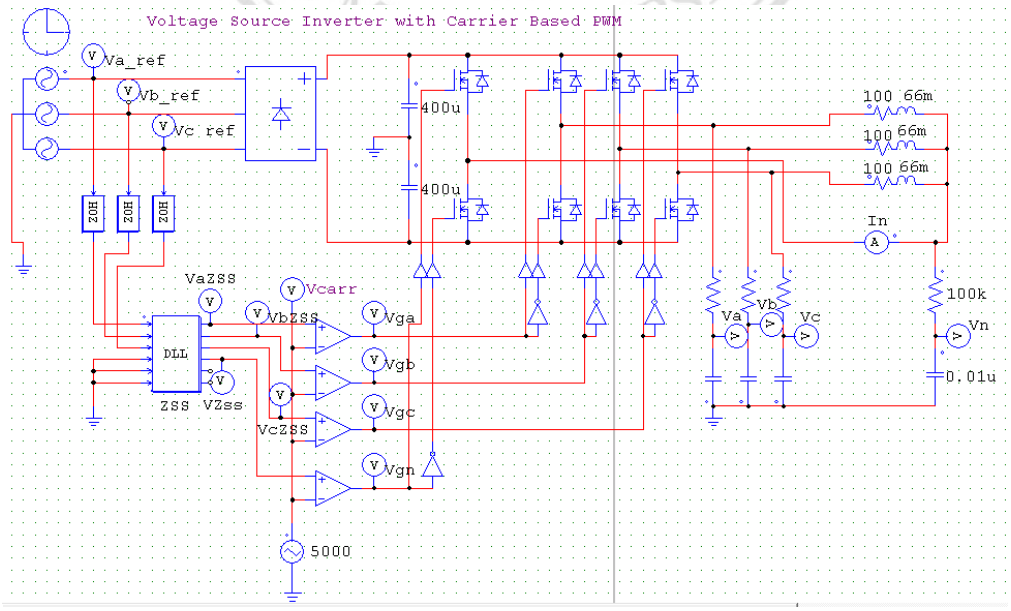


Figure 4.1 PSIM program simulation 3-phase 4-wire Voltage Source Inverter with Carrier-Based PWM Technique

In Figure 4.1 shows 3-phase 4-wire PSIM simulate circuit for testing voltage source inverter with CBPWM technique. The DLL block in PSIM program written in C language for calculate zero sequence signal from $V_{f0} = -\frac{(V_{\min} + V_{\max})}{2}$ the result of added ZSS shown in Figure 4.2-4.3 and $v_{a\_ref}, v_{b\_ref}, v_{c\_ref}$ is 380Vac voltage reference value.

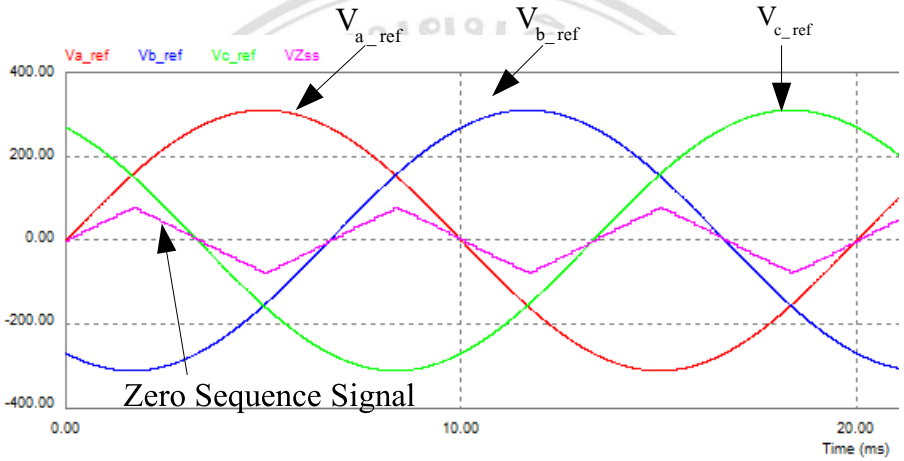


Figure 4.2 The result of Voltage v_a, v_b, v_c and V_{ZSS} Zero sequence signal PSIM simulation

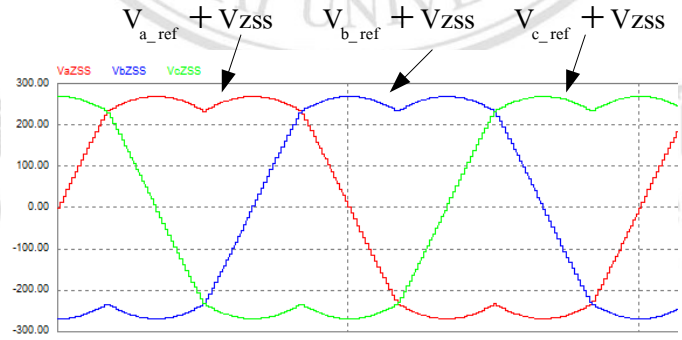


Figure 4.3 The result of Voltage v_{af}, v_{af}, v_{af} added V Zero sequence signal PSIM simulation

4.2 The result of simulation of voltage sags signal generator

4.2.1 PSIM simulation program to generated a voltage sags signal use 2 variable 1) percentage of voltage sags called P.U. and 2) sag duration time.

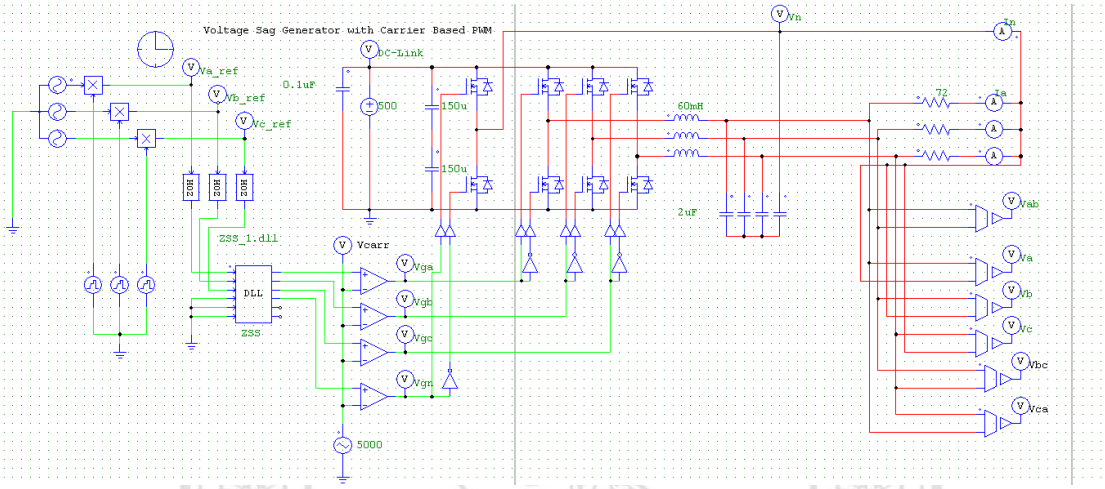


Figure 4.4 PSIM program simulation 3-phase 4-wire Voltage Sags CBPWM Technique

The result of simulation voltage sag generator CBPWM with %sag 0.5 p.u. or 50% of normal voltage and sag duration time 60ms voltage signal output shown in Figure 4.5

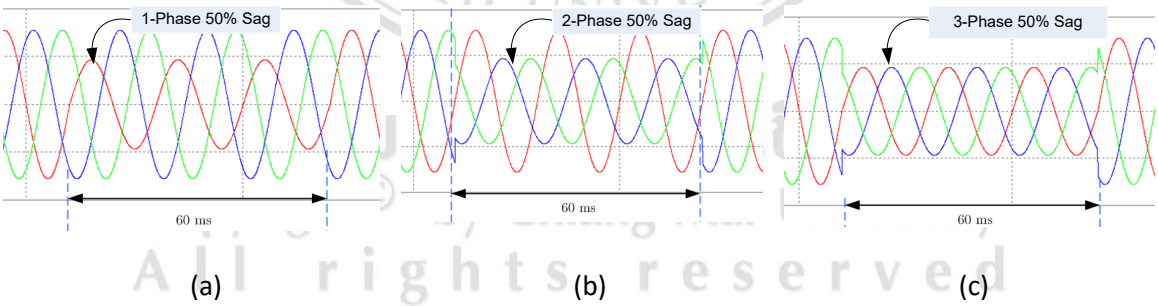


Figure 4.5. (a-c) The result of simulation CBPWM voltage sag generator from PSIM program (a) 1-Phase sag, duration time 60ms, Sag 50% PU., (b) 2-Phase sag, duration time 60ms, Sag 50% PU., (c) 3-Phase sag, duration time 60ms, Sag 50% PU.

4.2.2 The result of voltage sag signal from SagWave software MATLAB m-file GUI [26]

SagWave is software to help for easy to change parameter (5 parameter from chapter 3) of voltage sag generator and can preview voltage sag signal 7 type and can generate C command code send thought RS232 serial port to dsPIC microcontroller. Microcontroller has UART interrupt function for waiting command. Three command from SagWave is 1) configuration of 5 parameter and 2) start voltage source inverter and finally voltage sag starting command. But in this research not considered of SagWave the voltage sag generator can operate by self with 4x4 keypad with manual setting and 4 button using for start, stop, sag, and testing system fault SagWave software just use for preview voltage sags signal.

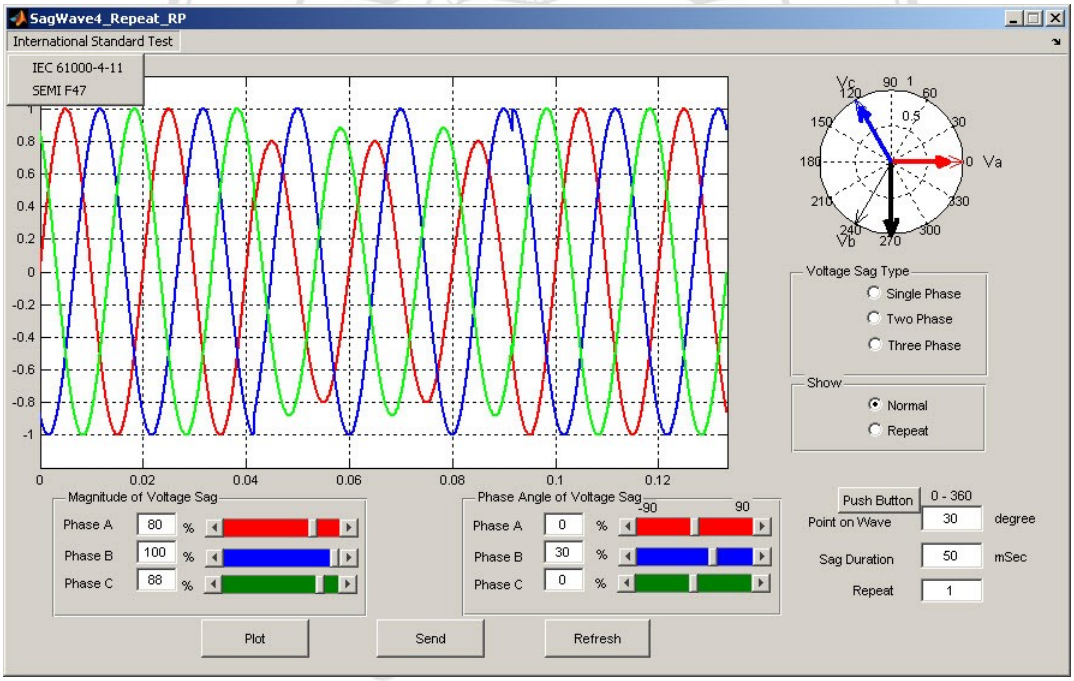
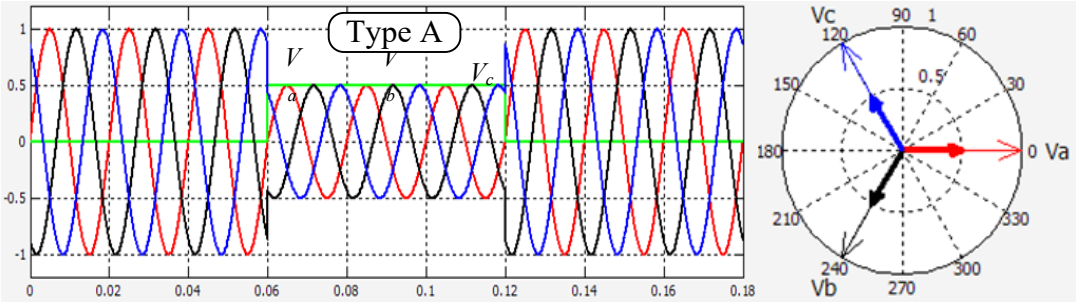


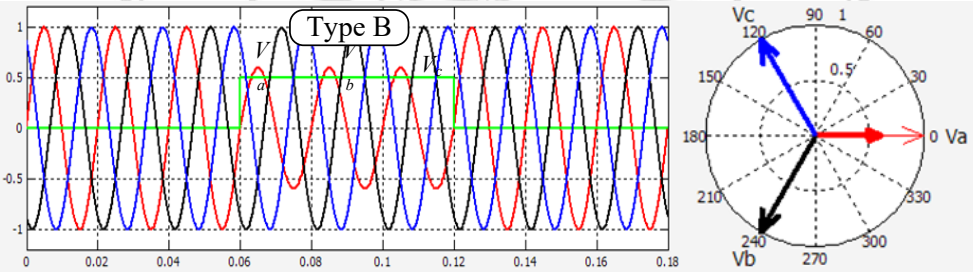
Figure 4.6 SagWave software program.

The layout of GUI designed as shown in Figure 4.6 The capabilities of GUI program allows user to define waveforms such as generate repetitive signal, according to SEMI F47 standard IEC 61000-4-11, created a 7-type of voltage sag, phase shift angle and point on wave of voltage sag. This GUI also display vector diagram of sag voltage and

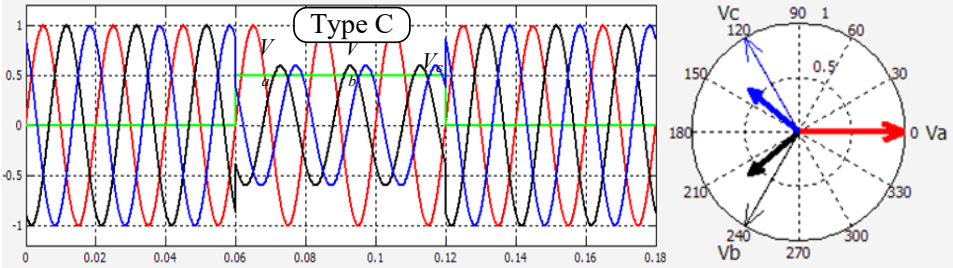
waveform for verification. Then, parameters of desired sag waveform can be sent to processor directly from GUI to generate the signal to D/A circuit. And the result of SagWave generate sags 7 types as shown in Figure 4.7 (a-g).



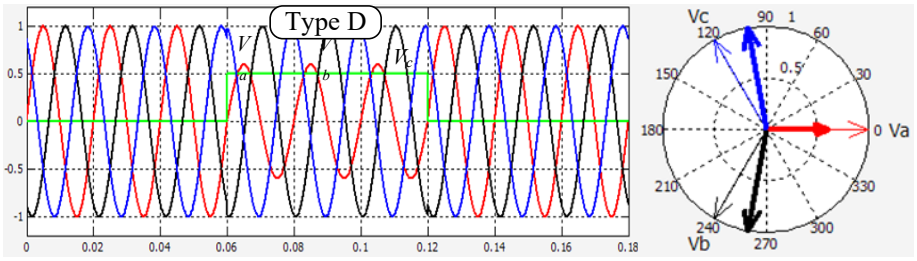
(a) Simulation result from SagWave GUI voltage sag type A



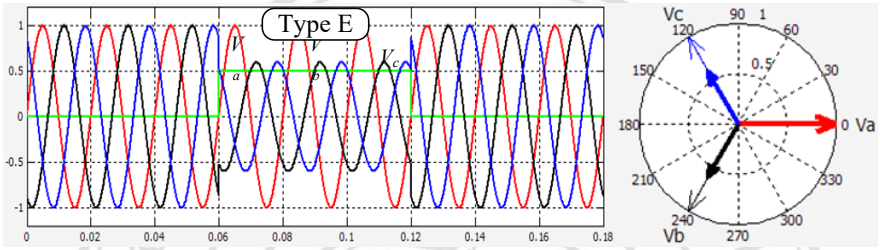
(b) Simulation result from SagWave GUI voltage sag type B



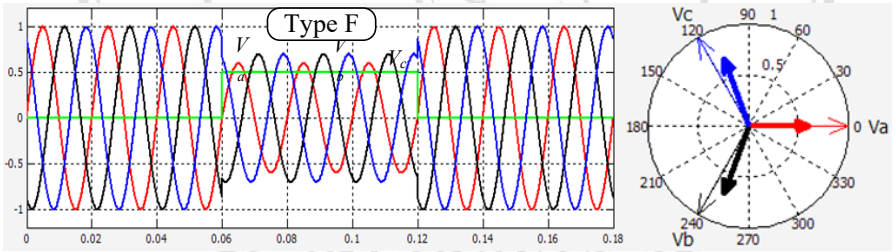
(c) Simulation result from SagWave GUI voltage sag type C



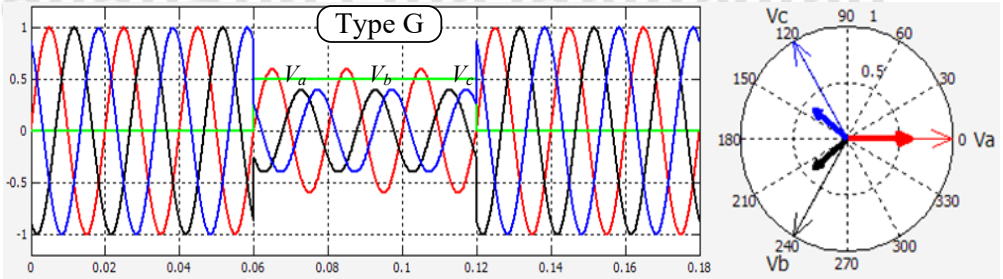
(d) Simulation result from SagWave GUI voltage sag type D



(e) Simulation result from SagWave GUI voltage sag type E



(f) Simulation result from SagWave GUI voltage sag type F



(g) Simulation result from SagWave GUI voltage sag type G

Figure 4.7 The result of SagWave MATLAB/GUI voltage sags type A-G simulation (a-g).

4.3 The resulte of 3-phase 4-wire voltage sags generator with CBPWM technique

The result of experimental tested three part. First, to test performance of voltage sags generator THDv and THDi and 2) test function of generate of 7 type sags signal and finally test electrical equipment with International standard test with diagram Figure 4.8

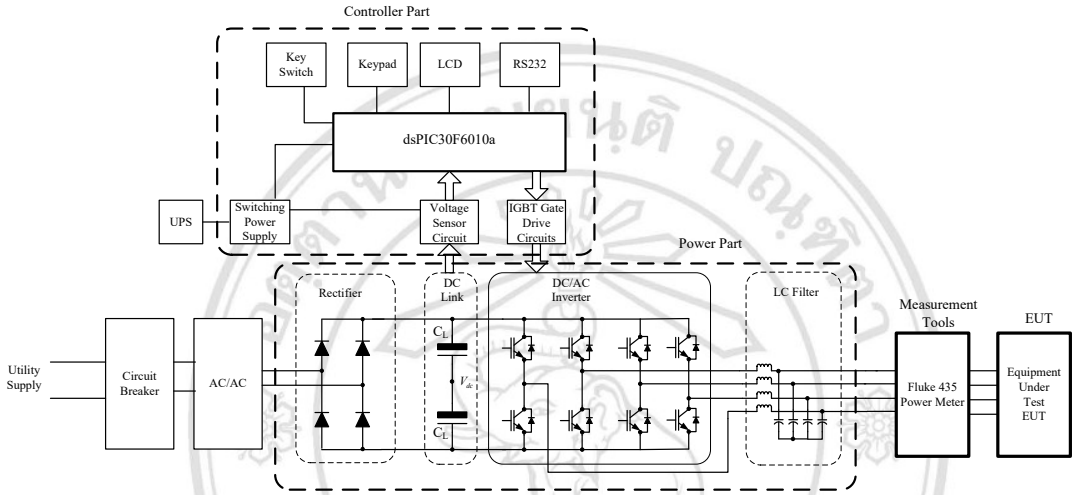


Figure 4.8 Voltage sags generator overall system.

And before use voltage sag signal generator for electrical equipment must be setting up default parameter such as number of phase to effect, percentage of voltage sag from p.u., sag duration time and point on wave. The variable are shown in figture 4.9

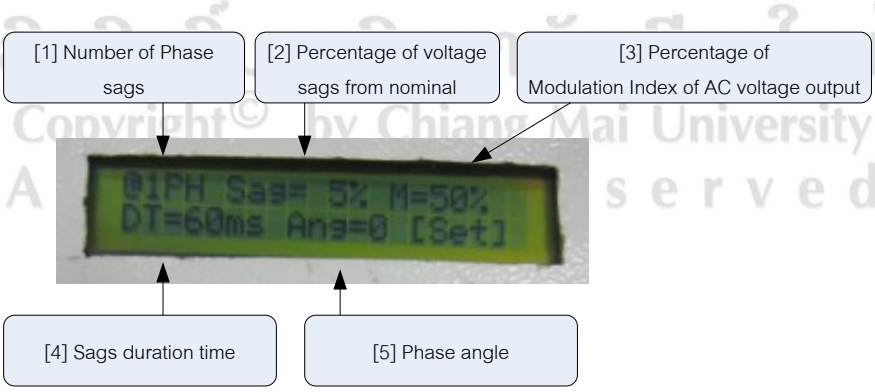


Figure 4.9 Setting up 5 variable before using voltage sags generator.

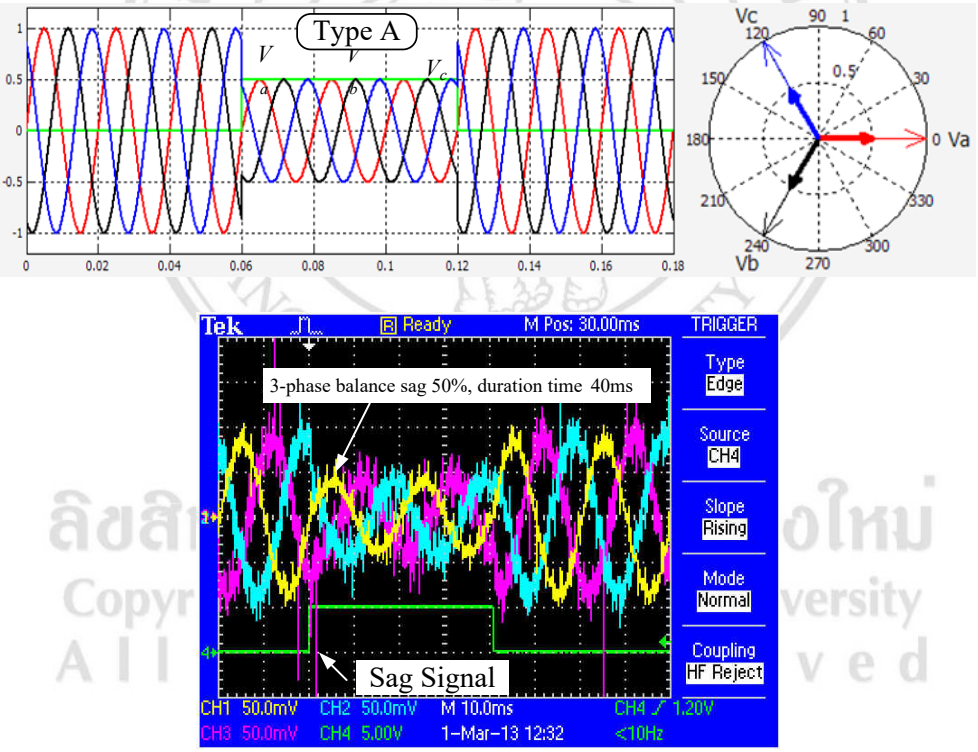
4.3.1 The result of voltage source inverter with LC Filter

Table 4.1 Power Electronics and component

Controllable switches	DC bus voltage	Carrier frequency	R*	C Filter	L Filter
IRG4PH40UD (1200V 21A)	500 V	5 kHz	72Ω	2μF	40mH

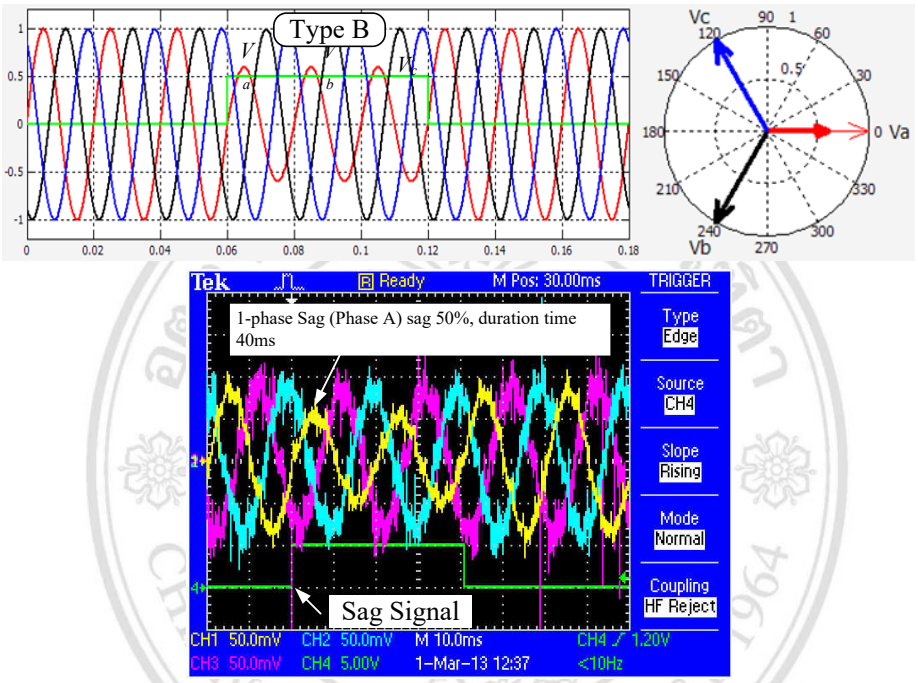
4.3.2 The result of voltage sags signal 7 types from Voltage Sags Generator.

The resulting of voltage sags signal type A as shown in Figure 4.10(a) all of three phase voltage sag at 50% P.U. and sags duration time 40ms.



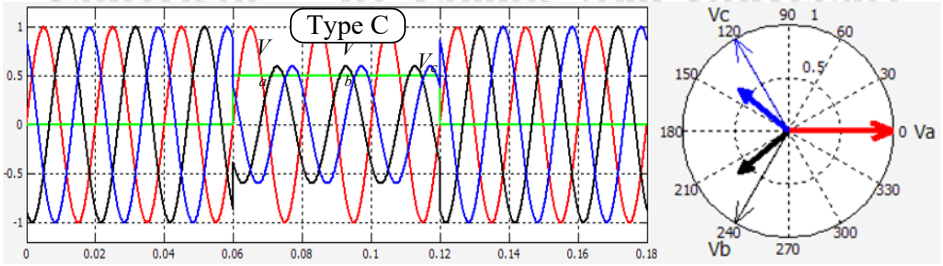
(a) Voltage sag signal type A 3 phase balanced 50% sag and 40ms time duration

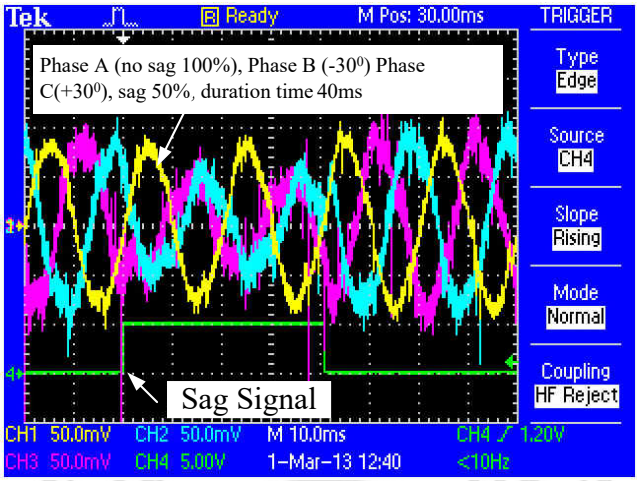
The resulting of voltage sags signal type B as shown in Figure 4.10(b) phase A has voltage sag at 50% P.U. and sags duration time 40ms.



(b) Voltage sag signal type B single phase 50% sag and 40ms time duration

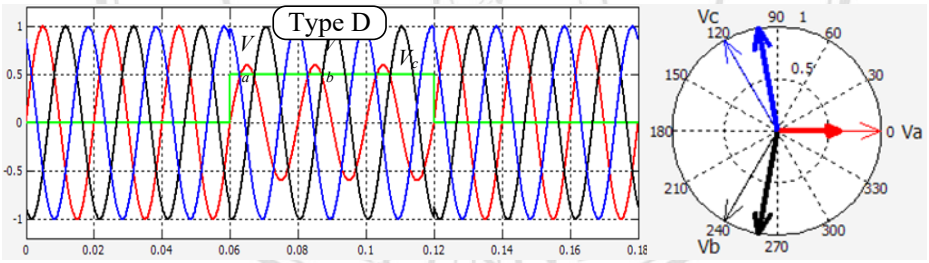
The resulting of voltage sags signal type C as shown in Figure 4.10(c) phase A has voltage nornally and phase B sag at 50% P.U. and phase shift leading 30 degree and phase C shift lagging 30 degree and sags duration time 40ms.

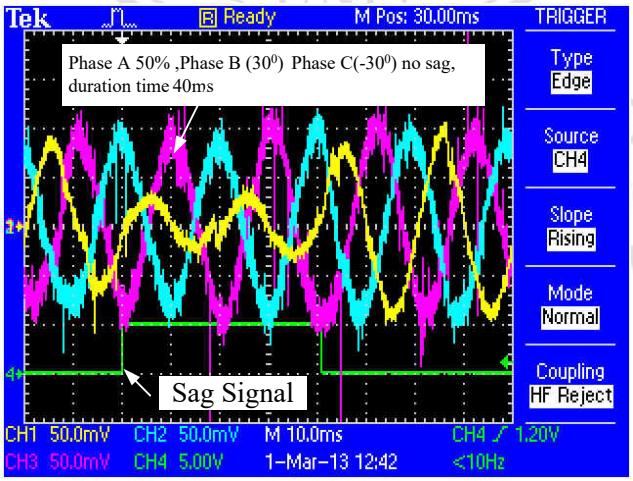




(c) Voltage sag signal type C phase-to-phase fault 50% sag and 40ms time duration

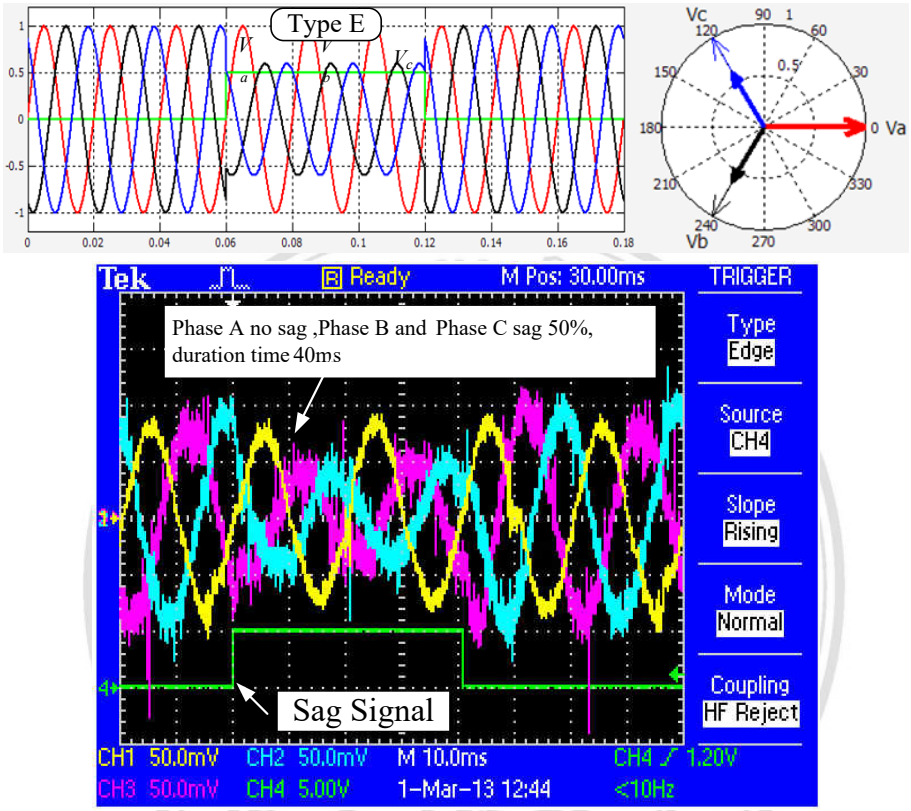
The resulting of voltage sags signal type D as shown in Figure 4.10(d) phase A has voltage sags 50% and phase B normally but phase shift lagging 30 degree and phase C shift leading 30 degree and sags duration time 40ms.





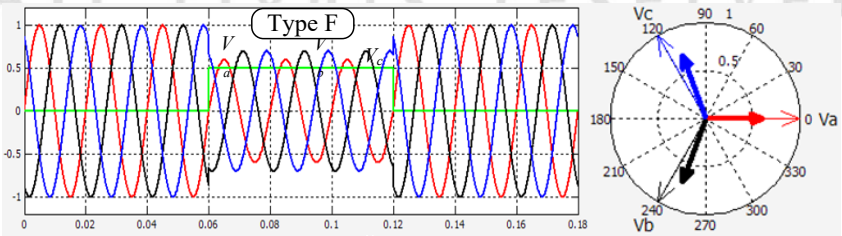
(d) Voltage sag signal type D Delta-connected Load phase-to-phase fault 50% sag and 40ms time duration

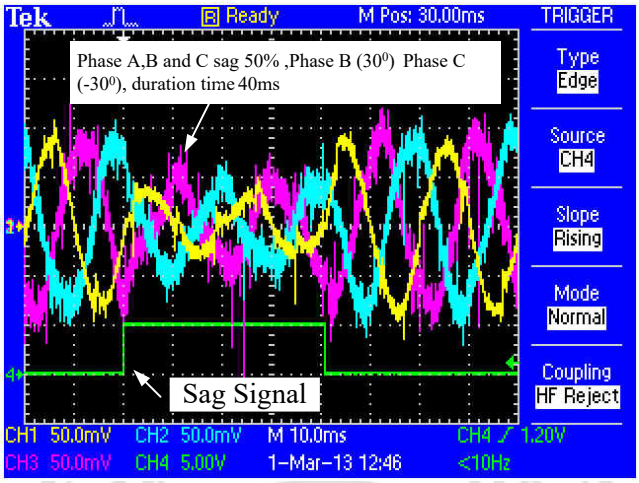
The resulting of voltage sags signal type E as shown in Figure 4.10(e) phase A has normal voltage and phase B and C voltage sags 50% and sags duration time 40ms.



(e) Voltage sag signal type E Two Phase to ground fault 50% sag and 40ms time duration

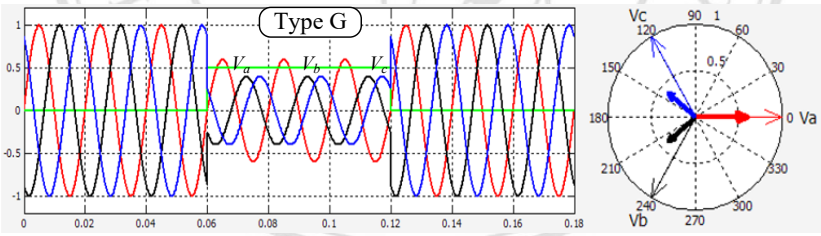
The resulting of voltage sags signal type F as shown in Figure 4.10(f) phase A has voltage sags 50% and phase B voltage sag 50% phase shift lagging 30 degree and phase C voltage sags 50% and phase shift leading 30 degree and sags duration time 40ms

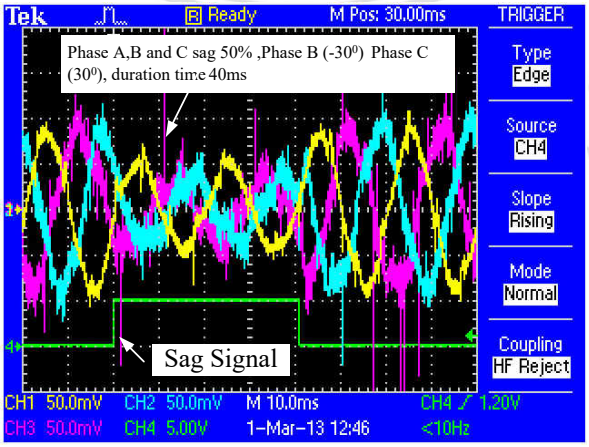




(f) Voltage sag signal type F Two Phase to ground fault delta connected load 50% sag and 40ms time duration

The resulting of voltage sags signal type F as shown in Figure 4.10(f) phase A has voltage sags 50% and phase B voltage sag 50% phase shift leading 30 degree and phase C voltage sags 50% and phase shift lagging 30 degree and sags duration time 40ms

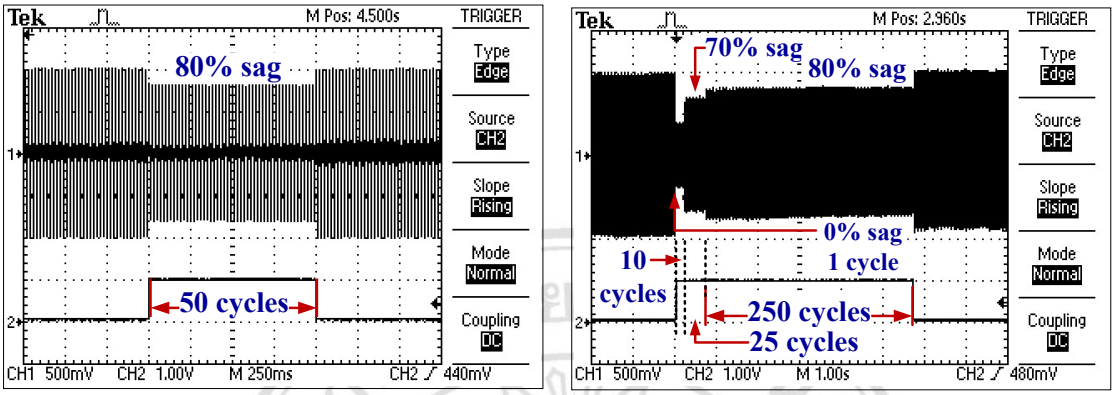




(g) Voltage sag signal type G Two Phase to ground fault delta connected load 50% sag and 40ms time duration

Figure 4.10 The result of Voltage Sags Generator Type A-G (a-g).

4.4 Testing electrical equipment immunity according to SEMI F47 and IEC 61000-4-11 class 3 are shown in figure. 4.11



(a) SEMI F47 standard waveform. (b) IEC 61000-4-11 class 3 waveform.

Figure. 4.11 The actual of SEMI F47 and IEC 61000-4-11 class 3 waveform.

4.5 The Electrical equipment immunity test

In this section to describe the equipment under test (EUT) under voltage sag. The experimental set up is shown in Figure 8. The EUT consists of voltage sag signal, the 3-phase inverter [10], gas discharge lamp, AC contactor, passive standby UPS (uninterruptable power supply) and high speed silicon photovoltaic detector (light sensor). The specification of the tested EUT is shown in Table 4.2 and Table 4.3

Table 4.2 Gas discharge lamp specifications

Gas discharge lamp type	Power rating	Ballast type
Fluorescent (FL1)	18W	Electromagnetic 220 V, 50 Hz, P.F. 0.35
Fluorescent (FL2)	36W	Electronic 220-240 V, 50/60 Hz, P.F. 0.6
High Intensity Discharge (HID, Mercury Lamp)	160W	Not use

Table 4.3 UPS specifications

Power	600VA/480W
Input Voltage	200±25% V
Input Current	2.27A
Input frequency	50 Hz ±10%
Output Voltage	200±10% V
Output Current	1.81A
Output frequency	50 Hz ±0.1%

Table 4.4 AC Contactor specifications

Coil voltage	220 V
Coil frequency	50/60 Hz
Hold-in power consumption	7 VA at 20°C (cos ϕ 0.3) 50 Hz 7.5 VA at 20°C (cos ϕ 0.3) 60 Hz

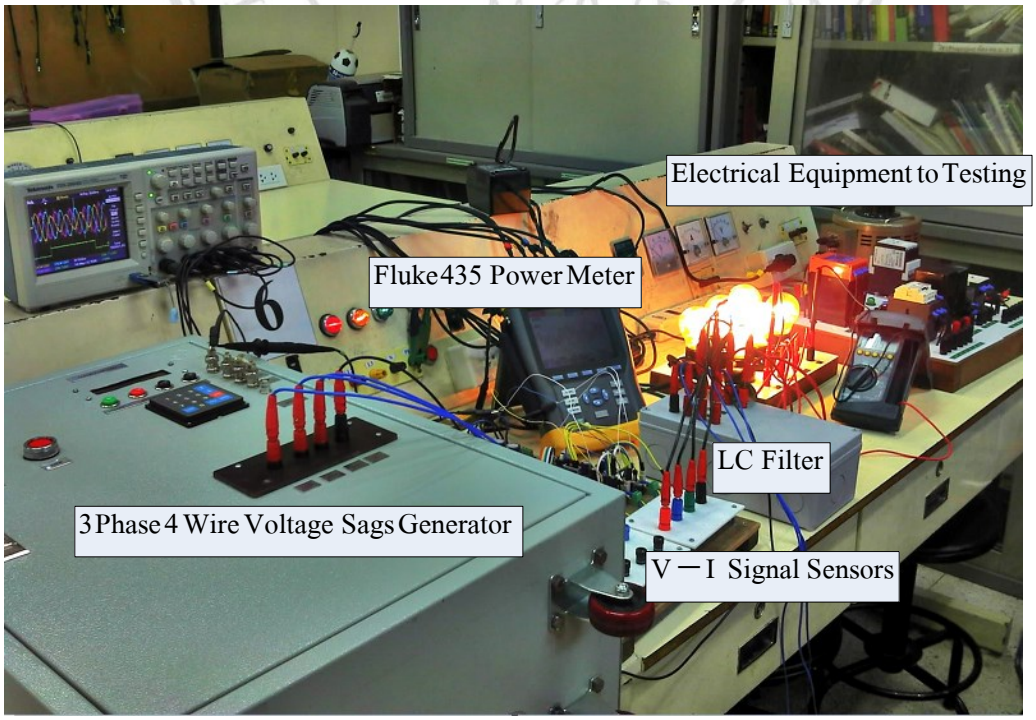


Figure. 4.12. The UPS immunity test under voltage sag.

Testing UPS following IEC 61000-4-11 standard with %sag and duration time in coordinate point Figure 4.13. Zone of operated of electric equipment separate 2 zone normal operating and shutdown. Test point near standard and operating point of specific of equipment.

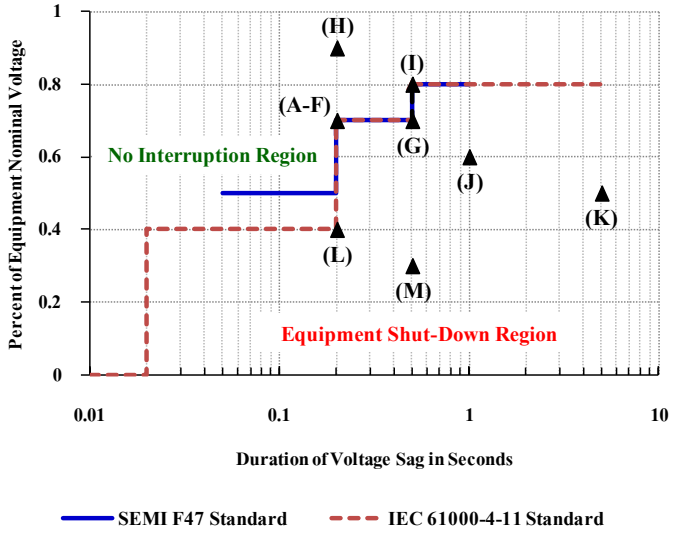
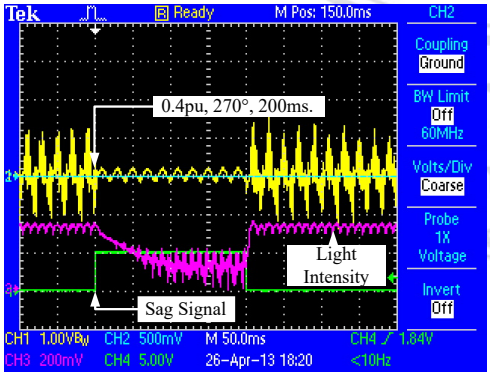
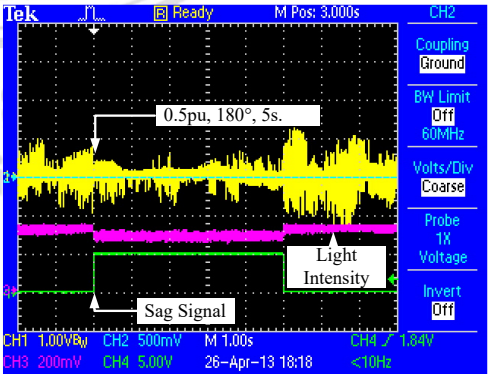


Figure. 4.13 Voltage tolerance curves of EUT

The methodology that is used in the testing is under SEMI F47 and IEC 61000-4-11 standard. The result of testing show in figure. 4.14 to figure. 4.19.

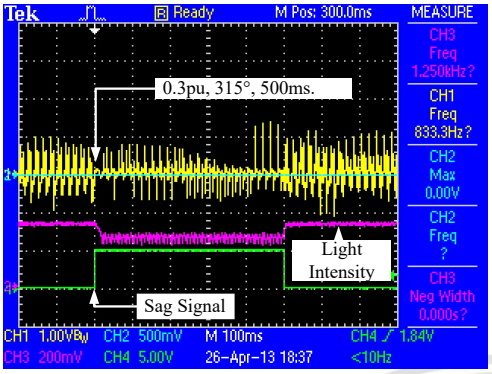


(a) 0.4pu, 200ms duration time (point L)

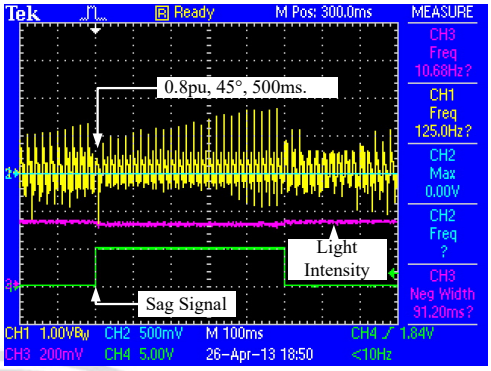


(b) 0.5pu, 5 s duration time (point K)

Figure 4.14 Waveform results of fluorescent lamp (FL1).

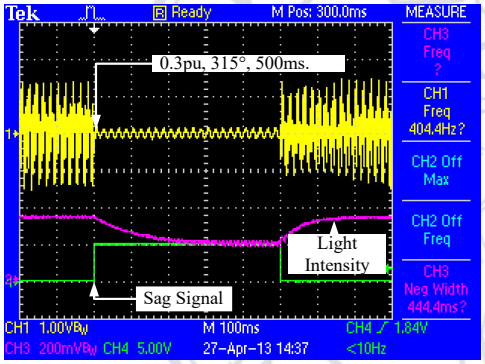


(a) 0.3pu, 500ms duration time (point M)

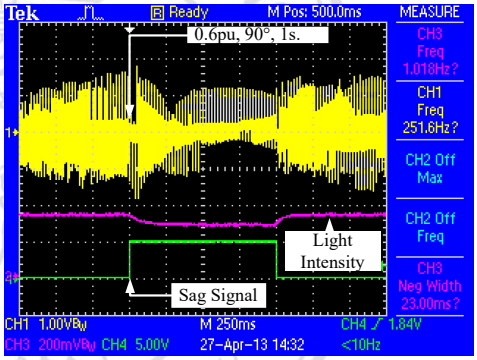


(b) 0.8pu, 500ms duration time (point I)

Figure 4.15 Waveform results of fluorescent lamp (FL2).

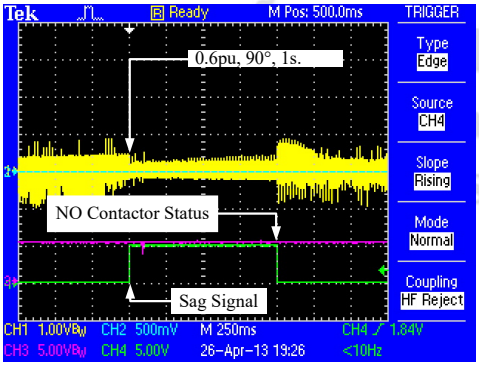


(a) 0.3pu, 500ms duration time (point M)

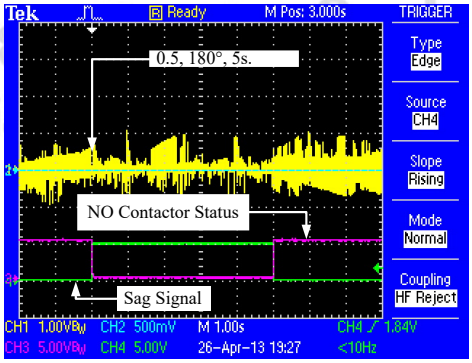


(b) 0.6pu, 1 s duration time (point J)

Figure 4.16 Waveform results of high intensity discharge lamp (HID).

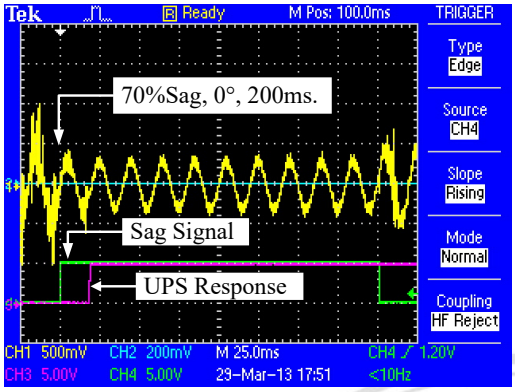


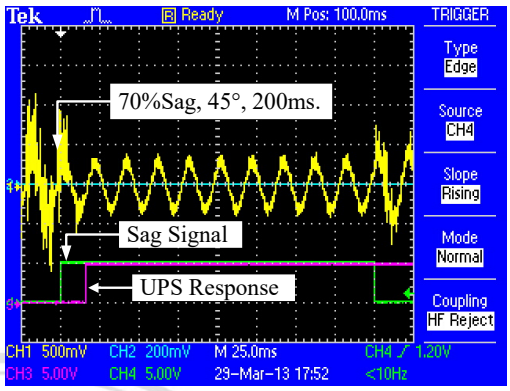
(a) 0.6pu, 1 s duration time (point J)



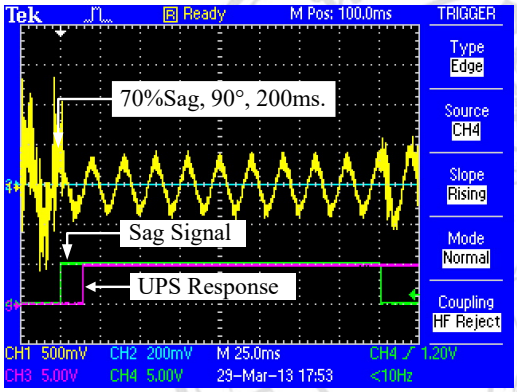
(b) 0.5pu, 5 s duration time (point K)

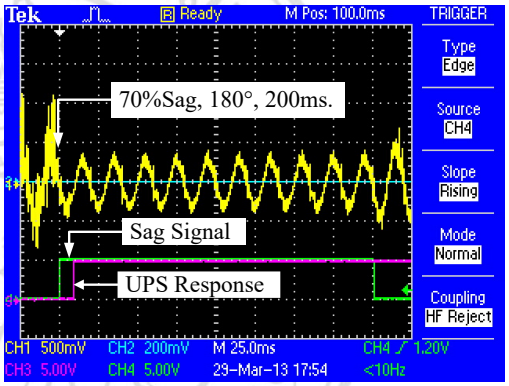
Figure 4.17 Waveform results of AC contactor.



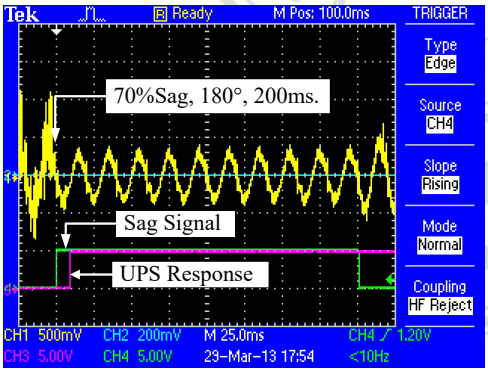


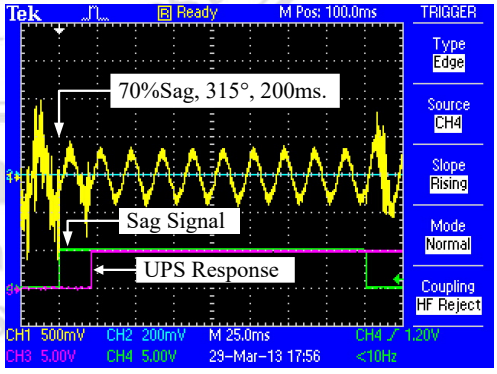
(a) 70% sag 10 cycles 0° point on wave (b) 70% sag 10 cycles 45° point on wave





(c) 70% sag 10 cycles 90° point on wave (d) 70% sag 10 cycles 180° point on wave





(e) 70% sag 10 cycles 180° point on wave (f) 70% sag 10 cycles 315° point on wave

Figure.4.18 70% voltage Sag, 200ms duration time. (point A to F)

Figure 4.18 shown result all of 70% sag (0.7p.u) duration time 200ms UPS testing and at any point on wave UPS will response in 20ms.

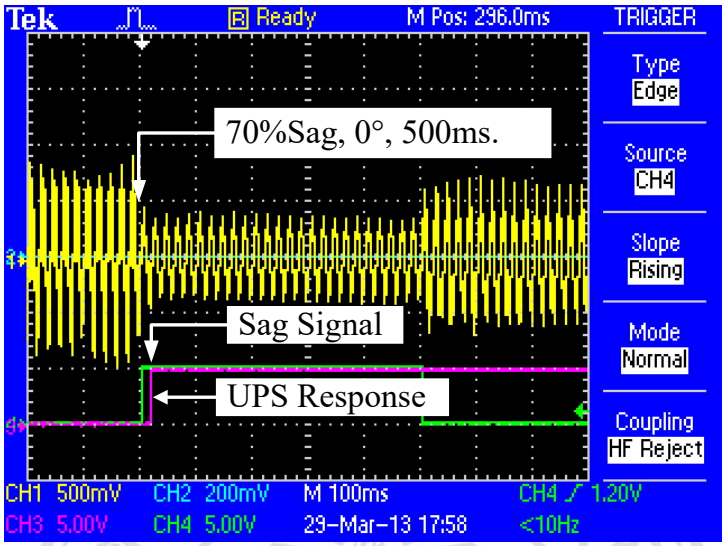


Figure. 4.19 70% voltage sag, 500ms duration time.(point G)

Figure 4.19 shown result of 70% sag (0.7p.u) duration time 500ms (SEMI F47) UPS testing UPS will response in 20ms (UPS specific ±25% nominal voltage)

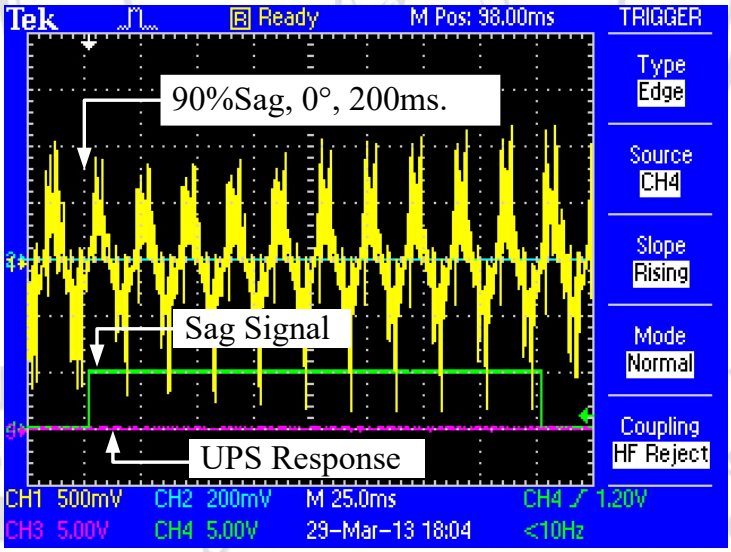


Figure. 4.20 90% voltage sag 200ms duration time. (point H)

Figure 4.20 shown result of 90% sag (0.9p.u) duration time 500ms (SEMI F47) UPS testing UPS will response in 20ms.

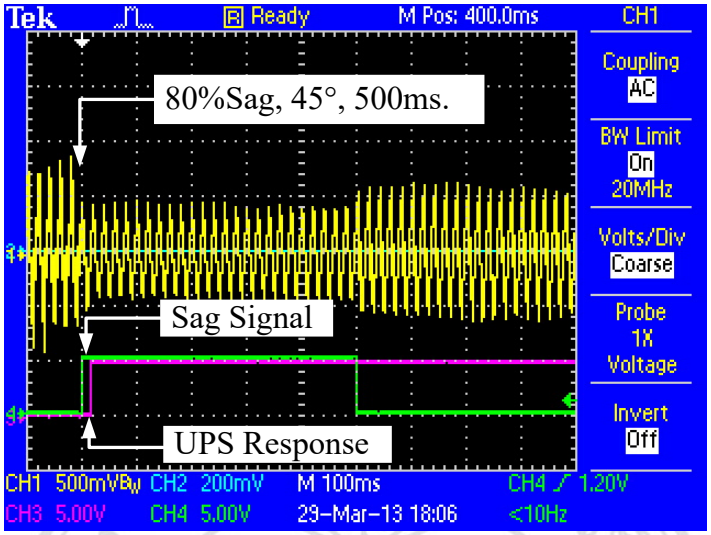


Figure. 4.21 80% voltage sag, 500ms duration time. (point I)

Figure 4.21 shown result of 80% sag (0.9p.u) 45° point on wave duration time 500ms (SEMI F47) UPS testing UPS not response.

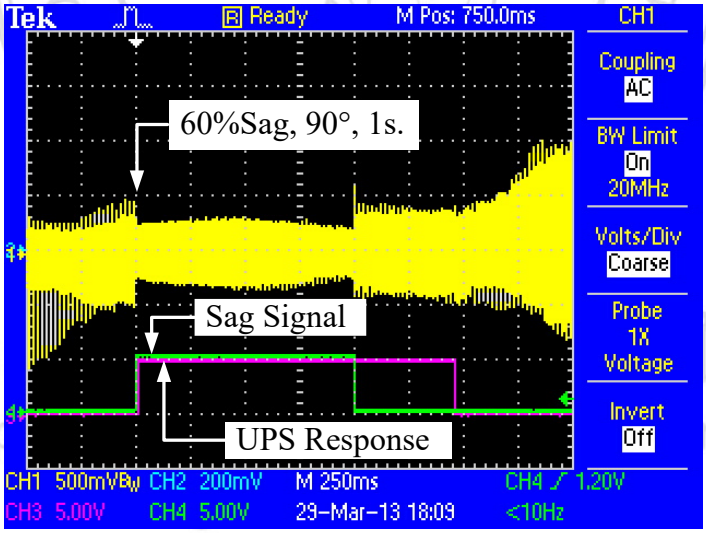


Figure. 4.22 60% voltage sag, 1 s duration time. (point J)

Figure 4.22 shown result of 60% sag (0.6p.u) 90° point on wave duration time 1 S (SEMI F47) UPS testing UPS will response in 20ms.

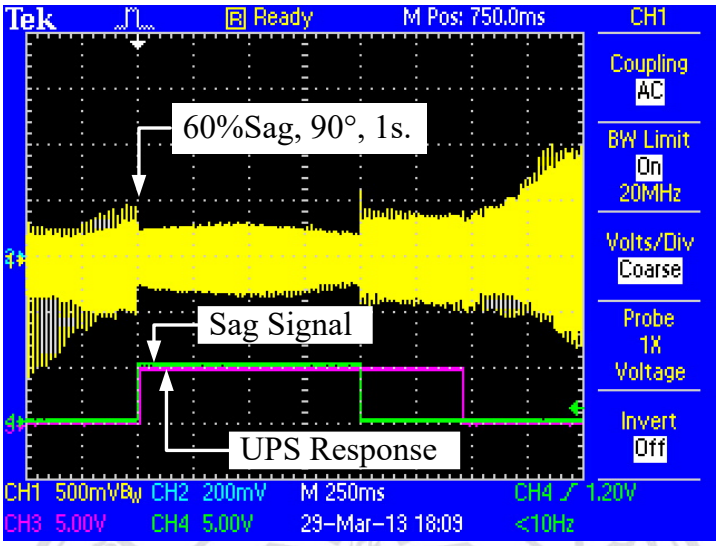


Figure. 4.23 60% voltage sag, 1s duration time. (point K)

Figure 4.23 shown result of 60% sag (0.6p.u) 90° point on wave duration time 1 S (SEMI F47) UPS testing UPS will response in 20ms.

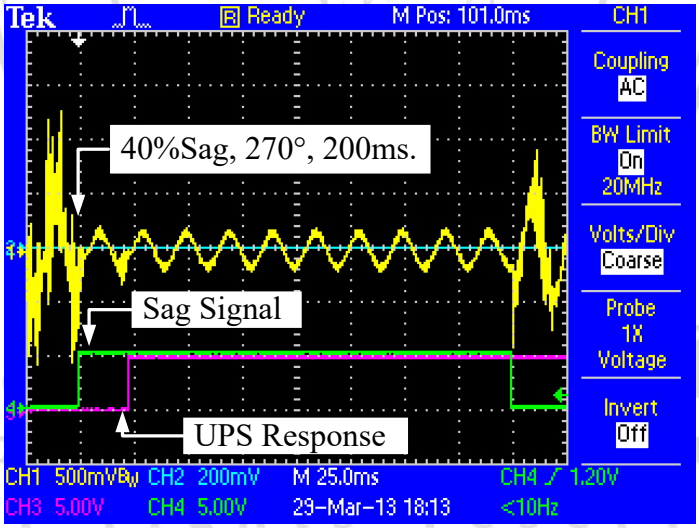


Figure. 4.24 40% voltage sag, 200ms duration time. (point L)

Figure 4.24 shown result of 40% sag (0.4p.u) 270° point on wave duration time 200ms (SEMI F47) UPS testing UPS will response in 20ms.

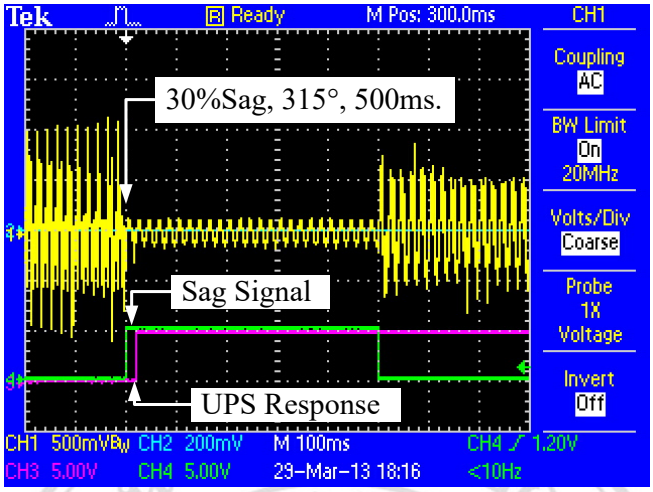


Figure. 4.25 30% voltage sag, 500ms duration time. (point M)

Figure 4.25 shown result of 30% sag (0.3p.u) 315° point on wave duration time 500ms (SEMI F47) UPS testing UPS will response in 20ms.

Table 4.5 Summary of test results

EUT	Point on curves												
	A	B	C	D	E	F	G	H	I	J	K	L	M
FL1	O	O	O	O	O	O	O	O	O	O	O	X	X
FL2	O	O	O	O	O	O	O	O	O	O	O	X	X
HID	O	O	O	O	O	O	O	O	O	O	O	O	O
UPS	O	O	O	O	O	O	O	O	O	O	O	O	O
AC Contactor	O	O	O	O	O	O	O	O	O	O	X	X	X

"O" = Good, "X" = Fail

(a) Fluorescent lamp: The FL1 and FL2 fail at L and M point. The operation at point L and M of FL1 was start and stop lighting, but FL2 the lighting was flicker. So, the FL1 and FL2 miss operation at voltage less than 40% and duration time more than 200ms.

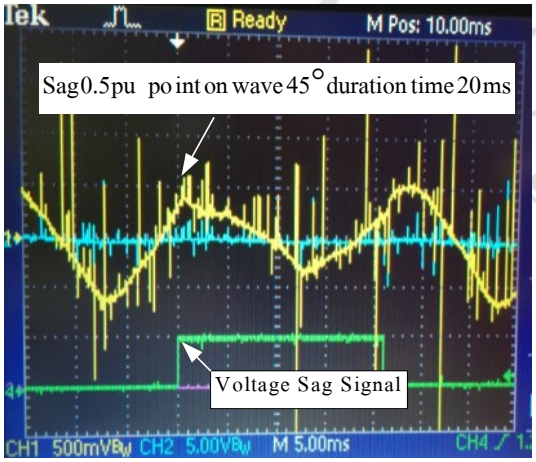
(b) HID lamp: The HID lamp was operated at all point in Figure 4.16, but the lamp intensity was reduced at voltage less than 40%.

(c) UPS : The UPS operated if magnitude of the sag is less than 40% nominal voltage and 200ms duration time. If the magnitude 70% - 80% and duration time greater than 500ms, the UPS was operated (shown with point G, I, J, K, L and M).

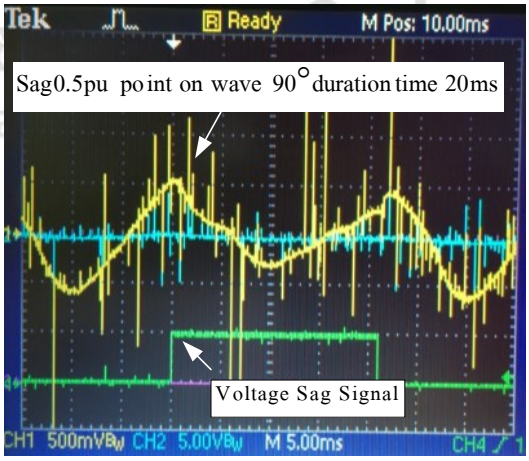
(d) AC contactor : The AC contactor was operated at point A to point J. At point J, voltage sag is 60%. The magnetizing of coil was reduced, but the contact of AC contactor still worked. At point K, L, M, the AC contactor stopped operation. The AC contactor miss operation at voltage less than 60% and time duration more than 200ms.

4.6 Point on wave

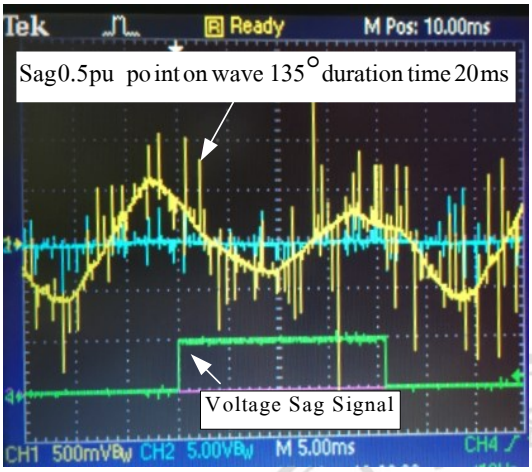
The point-on-wave initiation is the phase angle of the fundamental wave at which the voltage sag starts. This angle corresponds to the angle at which the short-circuit fault occurs. As most faults are associated with a flashover, they are more likely to occur near voltage maximum than voltage zero. Point on wave initiation and ending are phase angles at which instantaneous voltage starts and ends to experience reduction in voltage magnitude, i.e. between which the corresponding rms voltage is below the defined threshold limit. [30] shown results of the experiments magnetic contactor coil current is the primary factor that determines if contactors will remain engaged during sags and that there are other characteristics of a sag, such as point in wave, and in this reseach VSG can generate voltage sag signal start at any angle point on wave the result shown in Figure 4.26 (a-g)



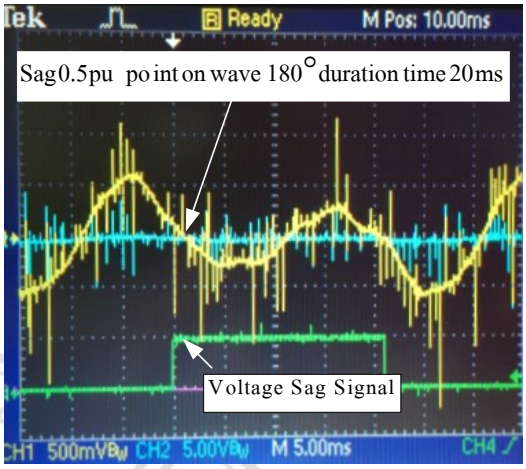
a) Sag 0.5pu 45° duration time 20ms



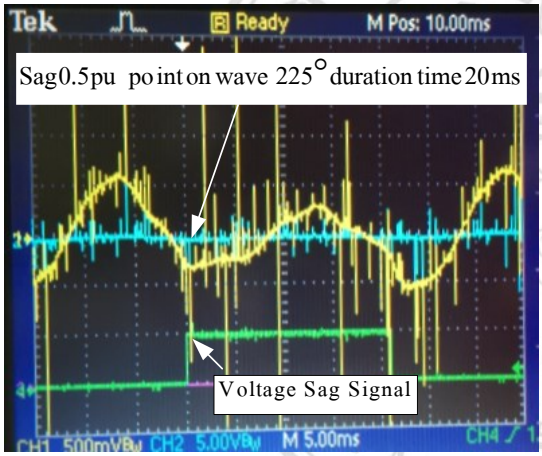
b) Sag 0.5pu 90° duration time 20ms



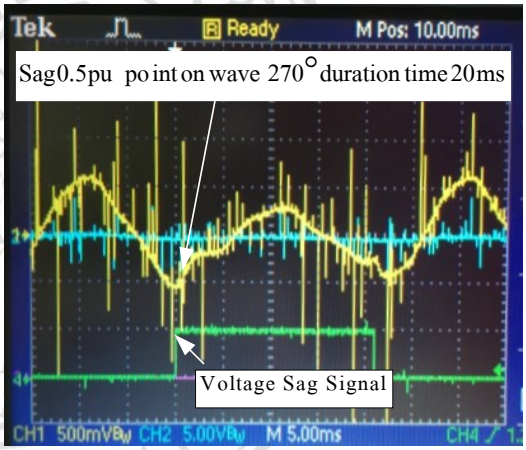
c) Sag 0.5pu 135° duration time 20ms



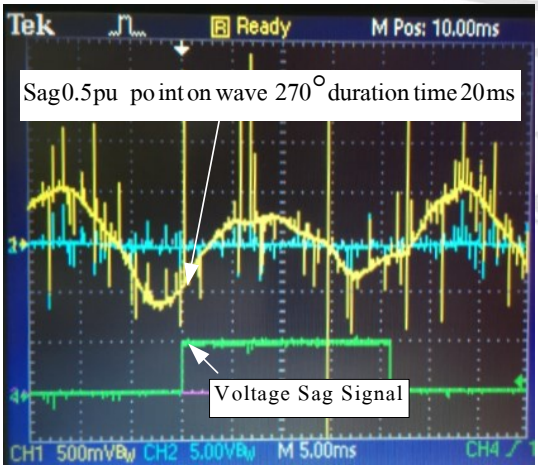
d) Sag 0.5pu 180° duration time 20ms



e) Sag 0.5pu 225° duration time 20ms



f) Sag 0.5pu 270° duration time 20ms



g) Sag 0.5pu 315° duration time 20ms

Figure 4.26 (a-g) VSG generate voltage sags signal at point on wave