Arnold Schwarzenegger
Governor

CERTS MICROGRID LABORATORY TEST BED

Tecogen CHP Modules Commissioning Report

APPENDIX E

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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Tecogen CHP Modules
Commissioning Report

Introduction

Tecogen, Inc. supplied (3) 60 kW, inverter-based, natural gas engine driven generators to the CERTS research program for the AEP Microgrid Test Bed. Tecogen subcontracted with Youtility Inc. (Hudson, NH) to supply the inverter cabinet. Each unit was packaged on a skid that includes the engine and its subsystems, synchronous generator, Youtility inverter, and the master control system. The master control system was equipped with a communications link to the Northern Power Energy Management System. The master control system also communicates internally with the inverter via a CAN Bus.

Each unit was also equipped with a separate energy storage device, or Surge Module that was also supplied by Youtility. It was packaged in a cabinet for wall mount at the test site. The Surge Module provides 20 kW of battery power for 250 milliseconds to assist the engine/ inverter's response to a step load when the unit is islanded.

All three units were extensively tested prior to shipment to the AEP test site. First, each inverter cabinet was bench-tested at Youtility both individually, and in pairs as a simulated microgrid. Rather than the engine/generator providing the input power, the grid was used as the power source. The purpose of this testing was to verify the implementation of the various microgrid software control algorithms.

Once the Youtility bench testing was complete, the three inverter cabinets were sent to Tecogen for final packaging with the engine/generator. Each module was then tested to verify the integration of the inverter with the engine/generator. The three Surge Modules were also included in the scope of the factory testing at Tecogen to verify their performance. Both phases of the factory testing were successfully completed with each unit meeting the requirements established by the CERTS technical team.

Commissioning of the units commenced in July of 2006. In general, there were some normal shakedown issues encountered in getting the units on line. The most significant problem discovered during the commissioning was the speed control of the engine. The inverter was designed to directly control the engine throttle, via an electronic actuator, to adjust the engine speed in reaction to the load. It was able to sufficiently accomplish this during normal grid-tie operation where load changes were gradual. However, the units had problems with step loads, even with the assistance of the surge module.

Although this feature was extensively tested at the Tecogen factory, only specific step loads were checked. The control software was tuned to be able to handle these, but it was not possible to check the wide range of possible step-load scenarios at the Tecogen factory. Although additional software tuning by Youtility at the AEP test site may have possibly resolved the problem, Tecogen and Youtility felt a more prudent resolution was to remove the inverter control of the engine speed and use a conventional engine governor. This modification was successfully implemented and the governor was set to control the engine at fixed speed. The engine was then able to reliably handle the various step loads.

However, the change in the method of speed control caused a problem with the surge modules. The inverter software was using the speed signal to trigger the on/off control of the surge modules. When the inverter speed control was disabled, it corrupted the surge module control sequence such that the batteries were allowed to discharge, but not recharge. As a result, all the batteries discharged to such a low level that most of them were permanently damaged. Once this problem was identified, the inverter software was modified and the batteries replaced. The surge modules then successfully operated with the independent governor speed control. Subsequently, the Commissioning Test Matrix was then successfully completed by AEP.

In the following section, the details of the commissioning are summarized in a tabular format. Several documents are referenced in the table and attached to this document, including the test matrix, commissioning checklists, and the test data collected throughout the process.

Tecogen Commissioning Summary

Date	Activity	Attendees	Events	Outstanding Issues
7/10/06- 7/12/06	Engine Commissioning	John Freeman (Tecogen)	• Got all three engines operating • See Attachments 2, 3, and 4	
7/26/06 – 7/28/06	Commissioning of inverters and surge modules	John Freeman (Tecogen) Jian Wen (Youtility)	• Corrected Phase Rotation • Ran each unit through individual step loads – islanded. • Paralleled all 3 units together – islanded. • Paralleled all 3 units to the grid and transferred from grid-tie mode to micro-grid mode. • Transferred generator from micro-grid mode to grid-tie mode. • Refer to Attachment 5	• Only could run engines in fixed speed mode – engine would stall with large step loads in variable speed mode • Even in fixed speed mode, engine would stall with 0 – 60 kW • Full Matrix testing not done • Required waveform data not collected • Load banks on generator feeders overheated
8/23/06	Execute Test Matrix in Fixed Speed Mode	John Freeman (Tecogen)	• Ran single unit step load tests on all three units • Frequency droop did not respond properly on all units for the 0 - 60 kW tests. The reason was because the load banks actually produced slightly more the 60 kW putting the software out of its control range. • Unit A2 had a software problem where the frequency droop was not functioning properly at all. It was later determined some of the software constants were inadvertently reset by AEP when testing the EMS system. • Refer to Attachment 6 and 7	• The single unit testing was redone on 8/28/06 by Dave Klapp of AEP. • Repeat testing of Units A1 and B1 at slightly less than 60 kW showed correct frequency droop response. • Refer to Attachments 8, 9, 10
9/19/06 – 9/21/06	Install commercial governor to maintain engine speed at a fixed value independent of Youtility's inverter software.	John Freeman (Tecogen)	• Governor control was successful • Individual unit island tests were completed on units A1, A2 and B1. Surge modules were energized. • Problem arose with units A1 and A2 unable to phase lock. • See Attachments 11 and 12	• The Microgrid interface board was removed from one of the units and brought back to be inspected by Youtility.

Date	Activity	Attendees	Events	Outstanding Issues
10/11/06 – 10/14/06	Correct phase lock problem of A1 and A2 Capture oscilloscope data on surge modules Complete test matrix for multiple units	Jian Wen (Youtility) Paolo Piagi (Youtility) John Freeman (Tecogen)	• Two CT's, installed on the feeders by AEP were found to be reversed causing the phase lock problem. This was corrected. • It was discovered that the testing that occurred after the governors had been installed damaged the surge modules. By disabling the Youtility engine speed control software, the surge module control was adversely affected. The batteries discharged to such a low value that they were permanently damaged. The software was updated on all three units. New batteries were obtained to repair the A2 surge module. The governor speed setting was reduced from 2000 rpm to 1750 rpm on A2 to allow the surge module to trigger. The single unit step-load tests were run on unit A2 and oscilloscope waveforms were obtained. The surge module function on unit A2 was found to be acceptable. • The Commissioning Test Matrix was completed on all three units. Units A1 and B1 had the surge modules off with the engine speed fixed at 2200 rpm. Unit A2 had the surge module functioning. All tests passed. • See Attachments 13 and 14	• New batteries for surge modules A1 and B1 were going to be obtained and installed by AEP. John Stevens was going to evaluate the surge module design to determine if any design changes or additional sensors, for diagnostics or fault detection, would be required before commencing with further testing. • Once the surge modules got back on line, AEP would redo the matrix testing for all three units.
1/ 07	Replace cylinder head on engine A2	Bob Buday (Tecogen)	• The cylinder head had a factory defect causing water to leak into the exhaust.	• None

ATTACHMENTS

1. Commissioning Test Matrix

	Microsource Generators		
Test Point	**A1**	**A2**	**B1**
Island Tests			
Individual Unit – Power Control Mode *Scheduled 7/11 – 7/12 by Tecogen*			
I.a.i	X	X	X
I.a.ii	X	X	X
I.a.iii	X	X	X
I.a.iv	X	X	X
I.a.v	X	X	X
I.a.vi	X	X	X
Two Unit-Power Control Mode *Scheduled 7/26 –7/28 by Tecogen & Youtility*			
II.c.i	X	X	
II.c.ii	X	X	
II.c.i	X		X
II.c.ii	X		X
Grid Tie Tests			
Two Unit –Power Control Mode *Scheduled 7/26 –7/28 by Tecogen & Youtility*			
II.a.i	X	X	
II.a.i		X	X
Two Unit – Mixed Mode *Scheduled 7/26 –7/28 by Tecogen & Youtility*			
III.a.i	X	X	
III.a.i		X	X
Grid Tie to Island Tests			
Two Unit –Power Control Mode *Scheduled 7/26 –7/28 by Tecogen & Youtility*			
II.b.i	X	X	
II.b.i		X	X
Two Unit – Mixed Mode *Scheduled 7/26 –7/28 by Tecogen & Youtility*			
III.b.i	X	X	
III.b.i		X	X

Attachment 2

TECOGEN

Natural Gas Engine-Driven Products

TECOCHILL®
TECOGEN®
TECOFROST™

Tecogen Generator Commissioning Plan

Revision 1, 06/09/06

Unit Serial Number: 200837 unit A1

Date: 7-11-06

By: John Freeman

Each Tecogen unit will go through the procedure presented in this document.

JP ___ I. Inspection

1. Inspect Exhaust System
   - ✓a. Self-supporting – no significant force applied to exhaust connection
   - b. Insulated and with fire - resistant roof penetration
   - ✓c. Proper termination that prevents rainwater from entering piping system

2. Inspect Natural Gas System
   - ✓a. Proper pipe size
   - b. Dead-end Lock-up type regulator
   - ✓c. Gas supply pressure: 10 – 28" wc

3. Inspect Engine Coolant and Oil systems for leaks.

JP ___ II. Energize Control Power

✓1. Ensure breaker on cabinet door is open.

2. Reconnect battery negative cable.

✓3. Energize 208 Volt power to coolant pump.

✓4. Close microprocessor switch to boot up control system.

✓5. Check all Input switch positions

Safety Switch	Position	Check
Low Engine Oil Level	On	✓
Low Coolant Pressure	Off	✓
Low Engine Oil Pressure	Off	✓
High Coolant Pressure	On	✓

6. Check all Temperatures

Thermistors	Record
Engine Coolant Temperature	77.6
Engine Oil Temperature	75.8
Ambient Temperature	74.9
~~High Coolant Pressure~~	
Water Temperature In	77.4
Water Temperature Out	77.3

2 of 4

7. Energize Outputs in Calibrate Mode

   a. Coolant System Pump
      i. Open shut-off valves to unit
      ii. Record System Static Pressure: _________
      iii. Energize Main System Circulating Pump
      iv. Record Inlet and Outlet Pressure of Main Pump
          Inlet Pressure: _________
          Outlet Pressure: _________
      v. Check Low Coolant Pressure Switch is "On"

   b. Natural Gas System
      i. Open shut-off valve to unit
      ii. Energize Gas Solenoid
      iii. Bleed Gas Line
      iv. Record Gas Pressure: 16" inlet   4" outlet

   c. Energize Inverter Control Power
      i. Record MAP Pressure: 28.9

   d. Energize Alarm Output

III. Start Engine – No Electric Power Output

✓1. Ensure breaker on cabinet door is still open.

✓2. Ensure system is set to Variable Speed mode.

✓3. Disconnect Field Control (J5).

✓4. Start engine and verify proper speed loop operation. It should shut down after approximately 10 seconds.

✓5. Reconnect Field Control.

✓6. Restart engine.

7. Check and record the following:
   a. Engine Timing: 30°
   b. Engine Oil Pressure: 50
   c. DC Bus Voltage: _________

8. Engine will shut down once PCS is energized.

III. **Generate Power using Load Bank (Static Switch Open)**

1. Close breaker on cabinet door.
2. Restart Engine
3. Apply 10 kW load. Check the following: 20 KW
   a. Speed Control
   b. Engine Temperatures
   c. Voltage and Current Output
   d. Verify Emergency Stop button
4. Restart and slowly bring load up to 60 kW. Continuously check the following:
   a. Speed Control
   b. Engine Temperatures
   c. Voltage and Current Output
5. Download 60 kW data with RMCS

____ IV. **Perform Step Load Tests** – Refer to Northern Power's Commissioning Plan – Section 10

1. 0 – 30 kW
2. 0 - 60 kW
3. 15 - 50 kW
4. 30 – 60 kW
5. 60 – 0 kW
6. 30 – 0 kW

4 of 4

Attachment 3

TECOGEN

Natural Gas Engine-Driven Products

TECOCHILL®
TECOGEN®
TecoFROST™

Tecogen Generator Commissioning Plan

Revision 1, 06/09/06

Unit Serial Number: 200836 unit 42

Date: 7-11-06

By: John Freeman

Each Tecogen unit will go through the procedure presented in this document.

JP **I. Inspection**

1. Inspect Exhaust System
   - ✓ a. Self-supporting – no significant force applied to exhaust connection
   - b. Insulated and with fire - resistant roof penetration Not Yet
   - ✓ c. Proper termination that prevents rainwater from entering piping system

2. Inspect Natural Gas System
   - ✓ a. Proper pipe size
   - ✓ b. Dead-end Lock-up type regulator
   - ✓ c. Gas supply pressure: 10 - 28" wc 16" static

3. Inspect Engine Coolant and Oil systems for leaks.

JP **II. Energize Control Power**

✓ 1. Ensure breaker on cabinet door is open.

✓ 2. Reconnect battery negative cable.

✓ 3. Energize 208 Volt power to coolant pump.

✓ 4. Close microprocessor switch to boot up control system.

✓ 5. Check all Input switch positions

Safety Switch	Position	Check
Low Engine Oil Level	On	✓
Low Coolant Pressure	Off	✓
Low Engine Oil Pressure	Off	✓
High Coolant Pressure	On	✓

6. Check all Temperatures

Thermistors	Record
Engine Coolant Temperature	72.2
Engine Oil Temperature	73.5
Ambient Temperature	78.7
~~High Coolant Pressure~~	—
Water Temperature In	72.2
Water Temperature Out	74.4

7. Energize Outputs in Calibrate Mode
    a. Coolant System Pump
        i. Open shut-off valves to unit
        ii. Record System Static Pressure: 15 psi
        iii. Energize Main System Circulating Pump
        iv. Record Inlet and Outlet Pressure of Main Pump
            Inlet Pressure: ________
            Outlet Pressure: ________
        v. Check Low Coolant Pressure Switch is "On"
    b. Natural Gas System
        i. Open shut-off valve to unit
        ii. Energize Gas Solenoid
        iii. Bleed Gas Line
        iv. Record Gas Pressure: 16"
    c. Energize Inverter Control Power
        i. Record MAP Pressure: 29.5
    d. Energize Alarm Output

III. Start Engine – No Electric Power Output

✓ 1. Ensure breaker on cabinet door is still open.

✓ 2. Ensure system is set to Variable Speed mode.

✓ 3. Disconnect Field Control (J5).

✓ 4. Start engine and verify proper speed loop operation. It should shut down after approximately 10 seconds.

✓ 5. Reconnect Field Control.

✓ 6. Restart engine.

✓ 7. Check and record the following:
    a. Engine Timing: 30°
    b. Engine Oil Pressure: 48
    c. DC Bus Voltage: 432

✓ 8. Engine will shut down once PCS is energized.

3 of 4

III. Generate Power using Load Bank (Static Switch Open)

1. Close breaker on cabinet door.
2. Restart Engine
3. Apply 10 kW load. Check the following:
   a. Speed Control
   b. Engine Temperatures
   c. Voltage and Current Output
   d. Verify Emergency Stop button
4. Restart and slowly bring load up to 60 kW. Continuously check the following:
   a. Speed Control
   b. Engine Temperatures
   c. Voltage and Current Output
5. Download 60 kW data with RMCS

IV. Perform Step Load Tests – Refer to Northern Power's Commissioning Plan – Section 10

1. 0 – 30 kW
2. 0 - 60 kW
3. 15 - 50 kW
4. 30 60 kW
5. 60 0 kW
6. 30 – 0 kW

Attachment 4

TECOGEN
Natural Gas Engine-Driven Products

TECOCHILL®
TECOGEN®
TecoFROST™

Tecogen Generator Commissioning Plan

Revision 1, 06/09/06

Unit Serial Number: 200835 unit B1

Date: 7-11-06

By: John Freeman

Each Tecogen unit will go through the procedure presented in this document.

JF **I. Inspection**

1. Inspect Exhaust System
   - ✓a. Self-supporting no significant force applied to exhaust connection
   - b. Insulated and with fire - resistant roof penetration *Stack not yet insulated.*
   - ✓c. Proper termination that prevents rainwater from entering piping system

2. Inspect Natural Gas System
   - ✓a. Proper pipe size
   - ✓b. Dead-end Lock-up type regulator
   - ✓c. Gas supply pressure: 10 - 28" wc *16"*

3. Inspect Engine Coolant and Oil systems for leaks.

JF **II. Energize Control Power**

✓ 1. Ensure breaker on cabinet door is open.

✓ 2. Reconnect battery negative cable.

✓ 3. Energize 208 Volt power to coolant pump.

✓ 4. Close microprocessor switch to boot up control system.

✓ 5. Check all Input switch positions

Safety Switch	Position	Check
Low Engine Oil Level	On	✓
Low Coolant Pressure	Off	✓
Low Engine Oil Pressure	Off	✓
High Coolant Pressure	On	✓

6. Check all Temperatures

Thermistors	Record
Engine Coolant Temperature	74.4
Engine Oil Temperature	74.3
Ambient Temperature	74.4
~~High Coolant Pressure~~	
Water Temperature In	73.9
Water Temperature Out	73.9

7. Energize Outputs in Calibrate Mode

   a. Coolant System Pump
      i. Open shut-off valves to unit
      ii. Record System Static Pressure: 15 psi
      ✓iii. Energize Main System Circulating Pump
      iv. Record Inlet and Outlet Pressure of Main Pump
      Inlet Pressure: ________
      Outlet Pressure: ________
      v. Check Low Coolant Pressure Switch is "On"

   b. Natural Gas System
      i. Open shut-off valve to unit
      ii. Energize Gas Solenoid
      iii. Bleed Gas Line
      iv. Record Gas Pressure: 16"

   c. Energize Inverter Control Power
      i. Record MAP Pressure: 29.4

   d. Energize Alarm Output

____ **III. Start Engine – No Electric Power Output**

✓1. Ensure breaker on cabinet door is still open.

✓2. Ensure system is set to Variable Speed mode.

✓3. Disconnect Field Control (J5).

4. Start engine and verify proper speed loop operation. It should shut down after approximately 10 seconds.

5. Reconnect Field Control.

6. Restart engine.

7. Check and record the following:
   a. Engine Timing: 30°
   b. Engine Oil Pressure: 49
   c. DC Bus Voltage: 452

8. Engine will shut down once PCS is energized.

3 of 4

III. Generate Power using Load Bank (Static Switch Open)

1. Close breaker on cabinet door.
2. Restart Engine
3. Apply 10 kW load. Check the following:
    a. Speed Control
    b. Engine Temperatures
    c. Voltage and Current Output
    d. Verify Emergency Stop button
4. Restart and slowly bring load up to 60 kW. Continuously check the following:
    a. Speed Control
    b. Engine Temperatures
    c. Voltage and Current Output
5. Download 60 kW data with RMCS

IV. Perform Step Load Tests – Refer to Northern Power's Commissioning Plan Section 10

1. 0 – 30 kW
2. 0 - 60 kW
3. 15 - 50 kW
4. 30 - 60 kW
5. 60 - 0 kW
6. 30 - 0 kW

5. CERTS Microgrid Initial Test at AEP (7/26/06 – 7/28/06)

- Fixed unit A1 speed control problem.
- Updated firmware for all 3 units.
- Tested each unit in variable speed mode using Zone 4 load bank.
  - Step up 30KW
  - Step down 30KW
  - Step up 60KW
  - Step down 60KW

- Paralleled A1 and A2 units. Set variable speed mode as initial test, however, engine control failed to handle 60KW step load.
  Changed to fix speed mode, and ran engine at 2070 RPW. Tested A1 and A2 using Zone 4 load bank.
  - Step up 60KW
  - Step down 60KW
  - Step up 90KW
  - Step down 90KW

  After certain run time, Zone 4 load bank was over heat and failed.

- Paralleled all 3 A1, A2 and B1 units together.
  Set engine control as fix speed mode, and engine speed at 2070 RPW. Used the load near the grid input site, and tested
  - Step up 50KW, + 50KW, + 50KW
  - \- 50KW, - 50KW, -50KW
  - Step up 100KW
  - Step down 100KW
  - Step up 150KW
    (performed this test few more times as John requested)
  - Step down 150KW
  - Step up 150KW, + 30 KW gradually
  - Step down 180KW
  - Step up 150KW, + 30 KW step, fail

- Turned on grid, turned on static switch.
  Set load bank to 150KW.
  Set all 3 units as power control mode and set power command to 10KW.
  Tied all 3 units to the grid in the sequence of A1, A2, and B1.
  Each unit exported about 10KW.
  Opened the grid switch, all 3 unit ran at micro-grid mode and power 150KW.

- Turned on grid, turned on static switch.
  Set load bank to 150KW.
  Set all 3 units as power control mode and set power command to 50KW.
  Tied all 3 units to the grid in the sequence of A1, A2, and B1.
  Each unit exported about 50KW.
  Opened the grid switch, all 3 unit ran at micro-grid mode and power 150KW.

- Turned on B1, and step 50KW load.
  Ran 30 min.
  Tuned on A1 and A2.
  Set load bank to 150KW.
  Ran 90 min.
  Shuted down all 3 units.

- Turned on B1.
  Set B1 as power control mode, and power command = 10KW.
  Set Zone 5 load bank = 15KW.
  Turned on gird.
  Set load bank near the grid to 50KW.
  Enable the static switch, few minuets later, static switch automatically closed, and B1 tied to the grid successfully.

- Turned on B1.
  Set B1 as power control mode, and power command = 10KW.
  Set Zone 5 load bank = 30KW.
  Turned on gird.
  Set load bank near the grid to 50KW.
  Enable the static switch, few minuets later, static switch automatically closed, and B1 tied to the grid successfully.

6. Test Log for 8-23-06

Time	Test	Unit	Load Bank	Load (kW)
10:06 am	Trigger Test			
10:49 am	I.a.i	A1	3	0-30
10:51 am	I.a.vi	A1	3	30-0
10:56 am	I.a.ii	A1	3	0-60
11:00 am	I.a.v	A1	3	60-0
11:04 am	I.a.iii	A1	3	15-50

Time	Test	Unit	Load Bank	Load (kW)
11:12 am	I.a.i	A2	4	0-30
11:16 am	Ignore data			
11:20 am	I.a.vi	A2	4	30-0
11:24 am	I.a.ii	A2	4	0-60
11:28 am	I.a.v	A2	4	60-0
11:32 am	I.a.iii	A2	4	15-50

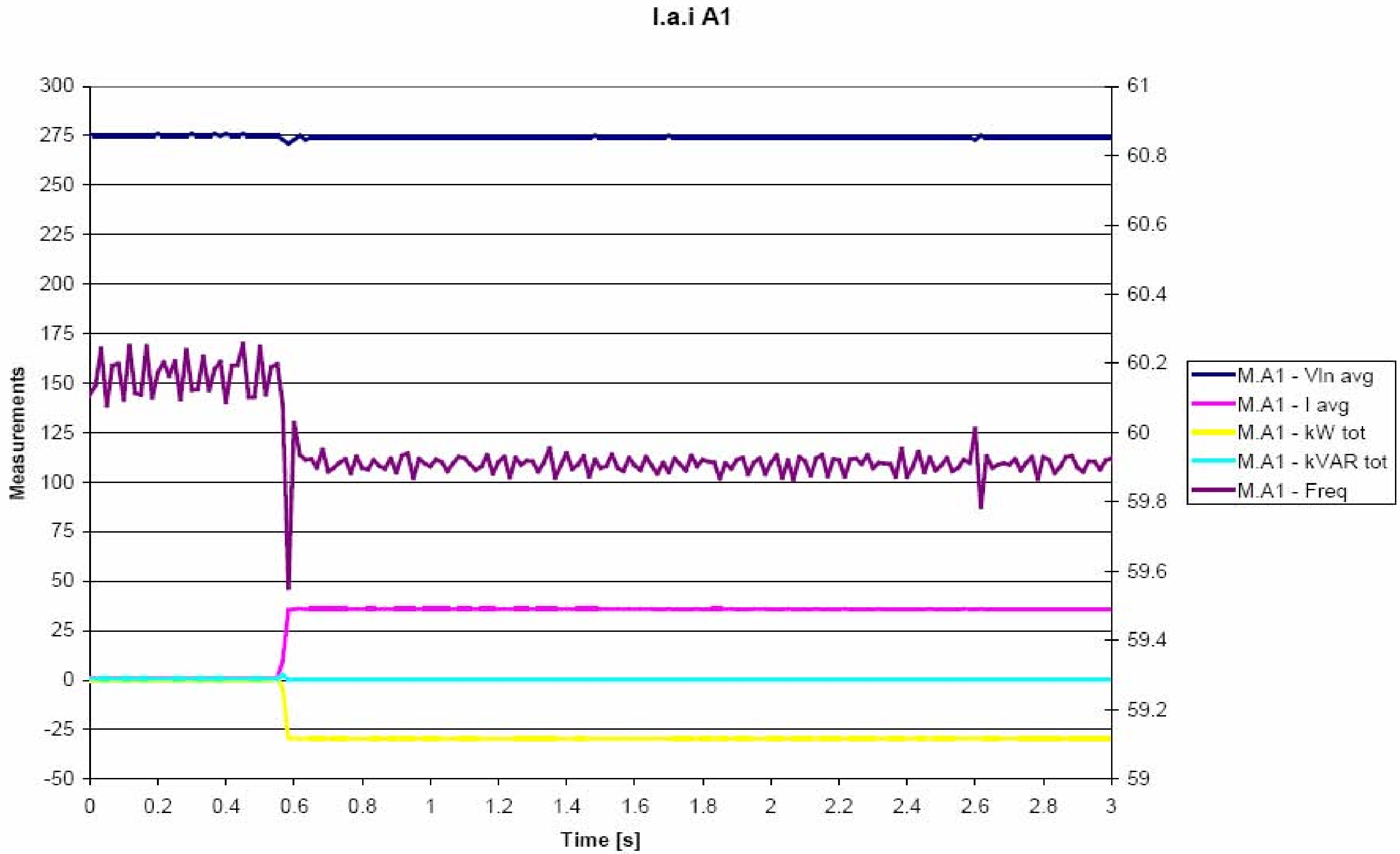
Time	Test	Unit	Load Bank	Load (kW)
11:46 am	Ignore Data (Engine Overspeed)			
11:56 am	I.a.i	B1	5	0-30
12:00 pm	I.a.vi	B1	5	30-0
12:04 pm	I.a.ii	B1	5	0-60
12:08 pm	I.a.v	B1	5	60-0
12:12 pm	I.a.iii	B1	5	15-50

Time	Test	Unit	Load Bank	Load (kW)
01:44 pm	Closed CB41 A1 was running with 50kW on Load Bank 3, No load on Load Bank 4			
02:15 pm	Generator A1 and A2 were load sharing 50kW, Generators carrying 50kW of load at 60Hz frequency, A2 performing as if it were Utility connected. Altering power output command would result in corresponding change in actual power output. We believe event was captured with a manual trigger.			

Note: “cpt” means cycles pre-trigger

03:10 pm	I.I.c.i (part2)(5 cpt)	A1*A2	3 50	
03:16 pm	I.I.c.i (part2)(13 cpt)	A1*A2	3 50	
03:26 pm	I.I.c.i (part3)	A1*A2	#3/50 #4/70	50-120

7. Test Results for 8-23-06



8. Test Log for 8-28-06

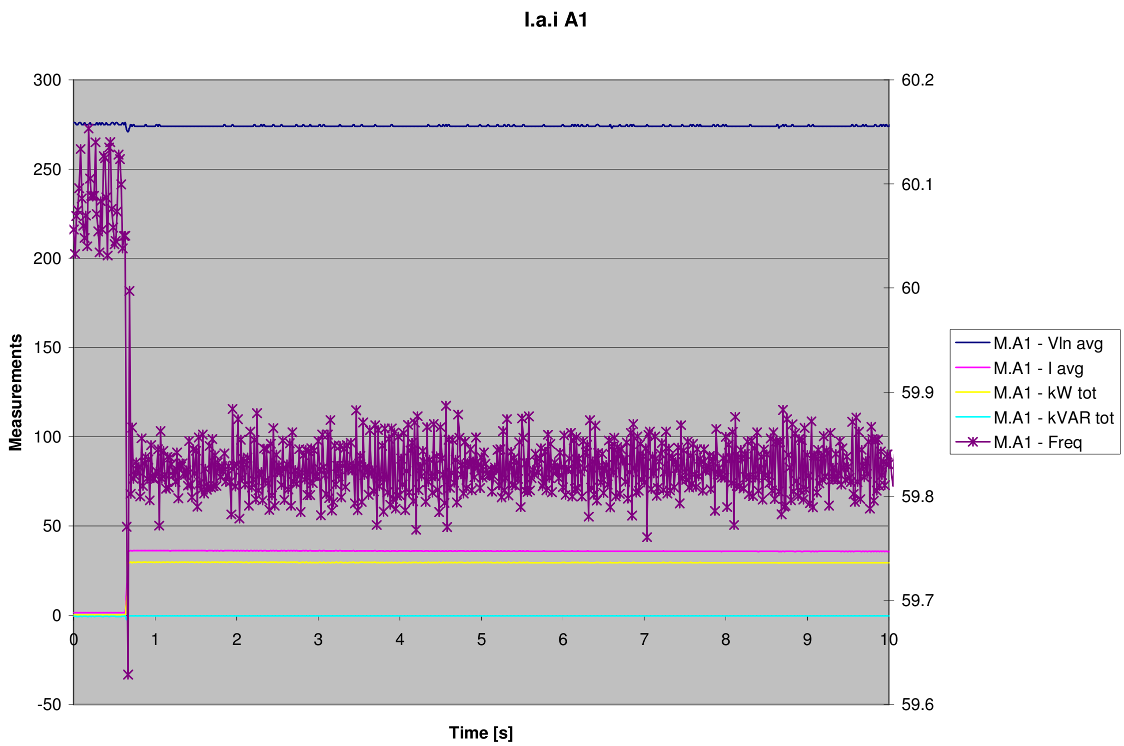
Time	Test	Unit	Load Bank		Load (kW)
Generator A1					
12:44 pm	Trigger Test				
12:58 pm	I.a.i	A1	3		0-30
1:03 pm	I.a.ii	A1	3		0-55
1:06 pm	I.a.iii	A1	3		15-45
1:09 pm	I.a.iv	A1	3		30-55
1:12 pm	I.a.v	A1	3		55-0
1:15 pm	I.a.vi	A1	3		30-0
1:28 pm	I.a.i	A2	4		0-30
1:31 pm	I.a.ii	A2	4		0-55
1:34 pm	I.a.iii	A2	4		15-45
1:37 pm	I.a.iv	A2	4	Genset No Field Sig	30-55
1:42 pm	I.a.iv	A2	4	Genset No Field Sig	30-55
1:46 pm	I.a.v	A2	4		55-0
1:49 pm	I.a.vi	A2	4		30-0
5:04 pm	I.a.i	B1	5	Genset Overspeed	0-30
5:08 pm	I.a.i	B1	5	Genset Overspeed	0-30
5:13 pm	I.a.ii	B1	5		0-55
5:16 pm	I.a.iii	B1	5	Genset No Field Sig	15-45
5:22 pm	I.a.iii	B1	5		15-45
5:25 pm	I.a.iv	B1	5	Genset No Field Sig	30-55
5:29 pm	I.a.iv	B1	5	Genset No Field Sig	30-55
5:37 pm	I.a.v	B1	5		55-0
5:40 pm	I.a.vi	B1	5		30-0

9. Test Log for 8-31-06

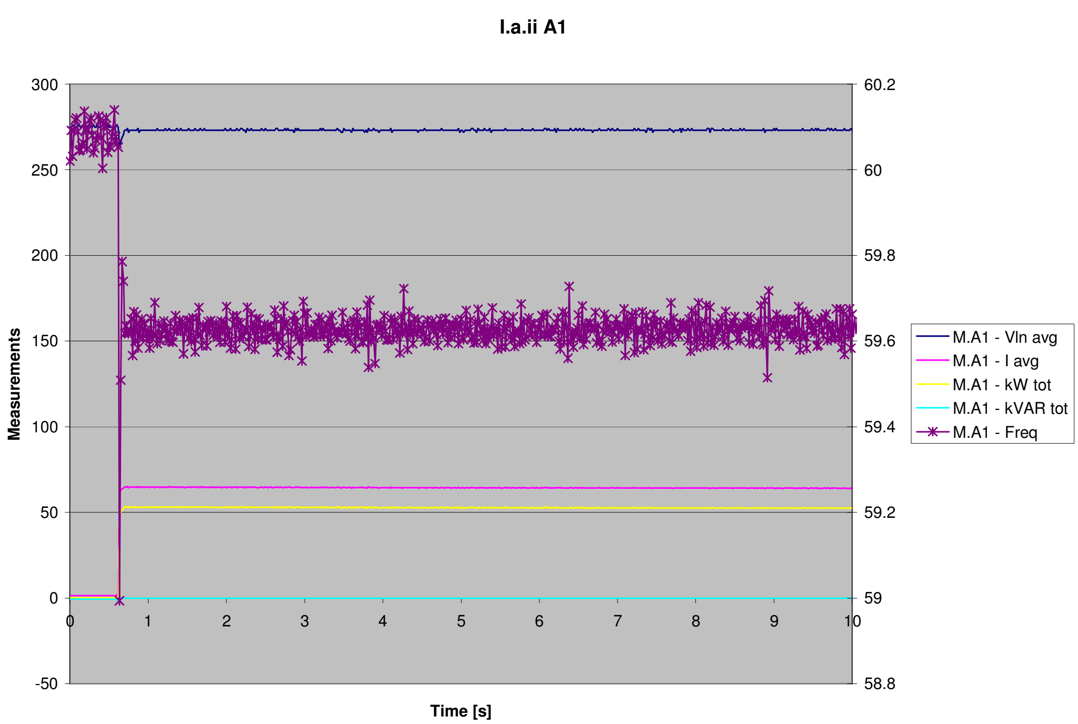
Time	Test	Unit	Load Bank		Load (kW)
Generator A1 and B1 w/out surge module					
8:22 am	II.c.i (Part 2)	A1+B1	3		55
	A1 initially loaded to 50kW, B1 was then connected.				
	Power Command: A1 = 6, B1 = 0				
8:27 am	II.c.i (Part 3)	A1+B1	3+5	Gensets Stalled	55-120
	A1 and B1 load step together. Power Command: A1 = 6, B1 = 0				
	A1 = No Field Sig, B1 = Boost Fault				
8:38 am	II.c.i (Part 2)	A1+B1	3		55
	A1 initially loaded to 50kW, B1 was then connected.				
	Power commanded: A1 = 0, B1 = 6				
	Repeated due to setpoint mismatch				
8:44 am	II.c.i (Part 3)	A1+B1	3+5	Gensets Stalled	55-120
	A1 and B1 load step together. Power Command: A1 = 0, B1 = 6				
	A1 = No Field Sig, B1 = Boost Fault				
8:54 am	Custom Test	A1+B1	3+5	Gensets Stalled	55-115
	A1 and B1 load step together. Power Command: A1 = 0, B1 = 6				
9:01 am	Custom Test	A1+B1	3+5	Gensets Stalled	50-120
	A1 and B1 load step together. Power Command: A1 = 0, B1 = 6				
	A1 = No Field Sig, B1 = Boost Fault				
9:15 am	II.c.ii	A1+B1	3		95-0
	A1 and B1 load step together. Power Command: A1 = 0, B1 = 6				
	Altered test because a single load step of 95kW is the maximum possible.				
9:49 am	Ignore Data Trigger Test of CB12 Opening				
10:16 am	II.a.i	A1+A2	3+4		30-90
	A1 and A2 load step together. Power Command: A1 = 20, A2 = 40				
10:23 am	II.b.i	A1+A2	3+4		40
	A1 and A2 Island Power Command: A1 = 6, A2 = 54				
11:12 am	II.a.i	A1+B1	3+5		30-90
	A1 and B1 load step together Power Command: A1 = 40, B1 = 20				
11:18 am	II.b.i	A1+B1	3+5	Genset Stalled	40
	B1 and A1 island Power Command: A1 = 54, B1 = 6				
11:35 am	II.b.i	A1+B1	3+5	Genset Stalled	40
	B1 and A1 island Power Command: A1 = 54, B1 = 6				

10. Test Results for 8-31-06

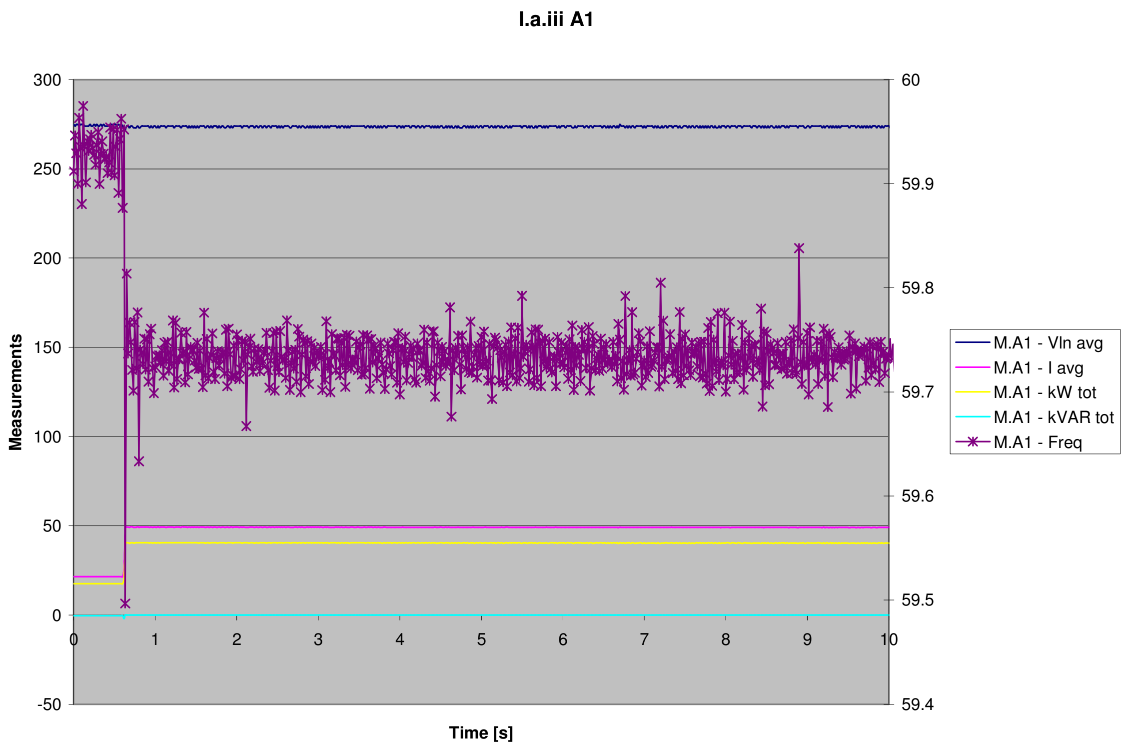
Test I.a.i A1 = 0 – 29.5kW load step



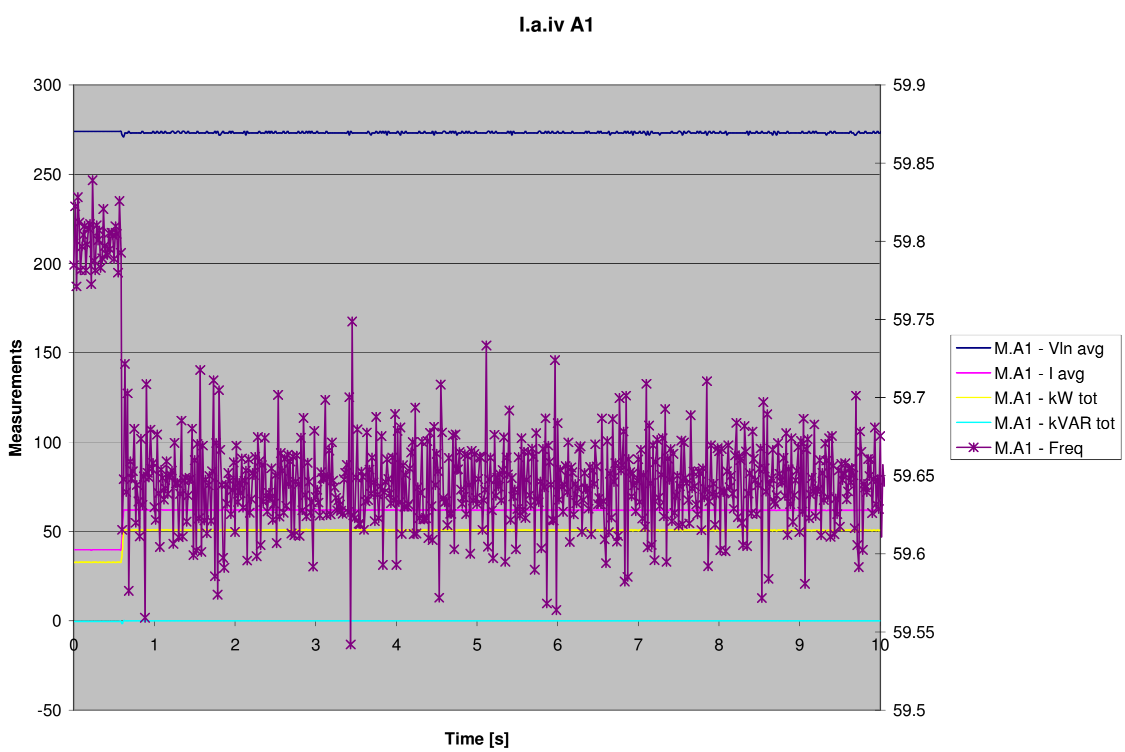
Test I.a.ii A1 = 0 – 53kW load step



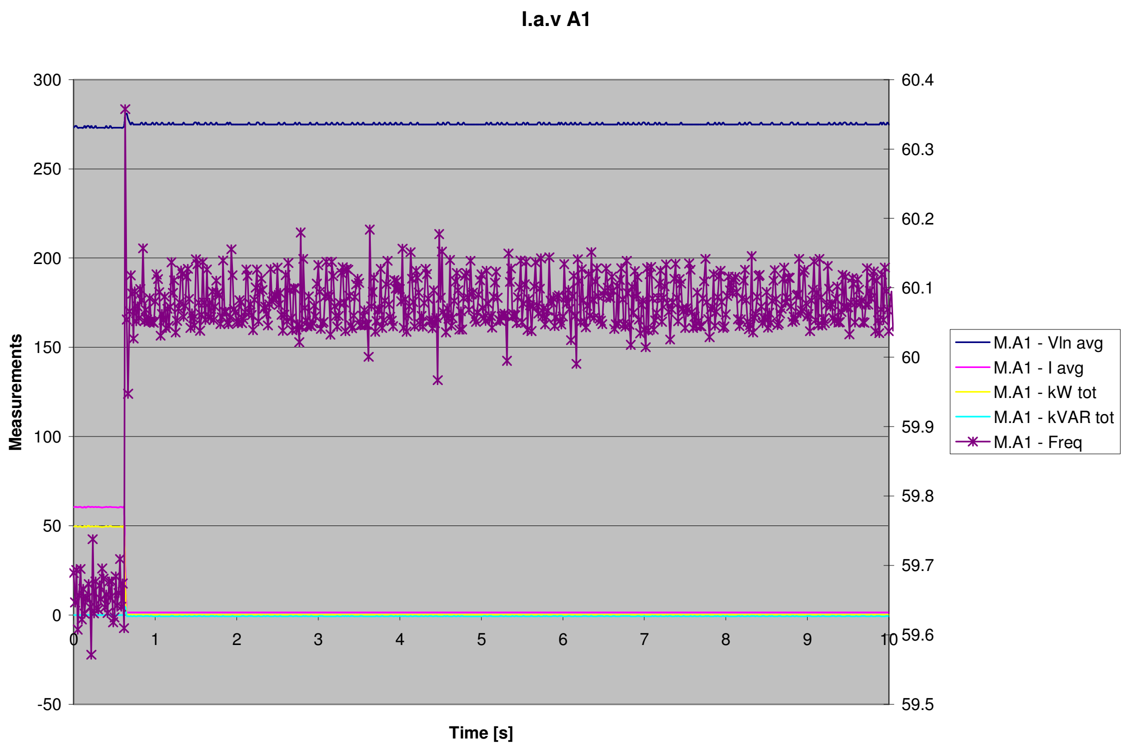
Test I.a.iii A1 = 17.6 – 40.5kW load step



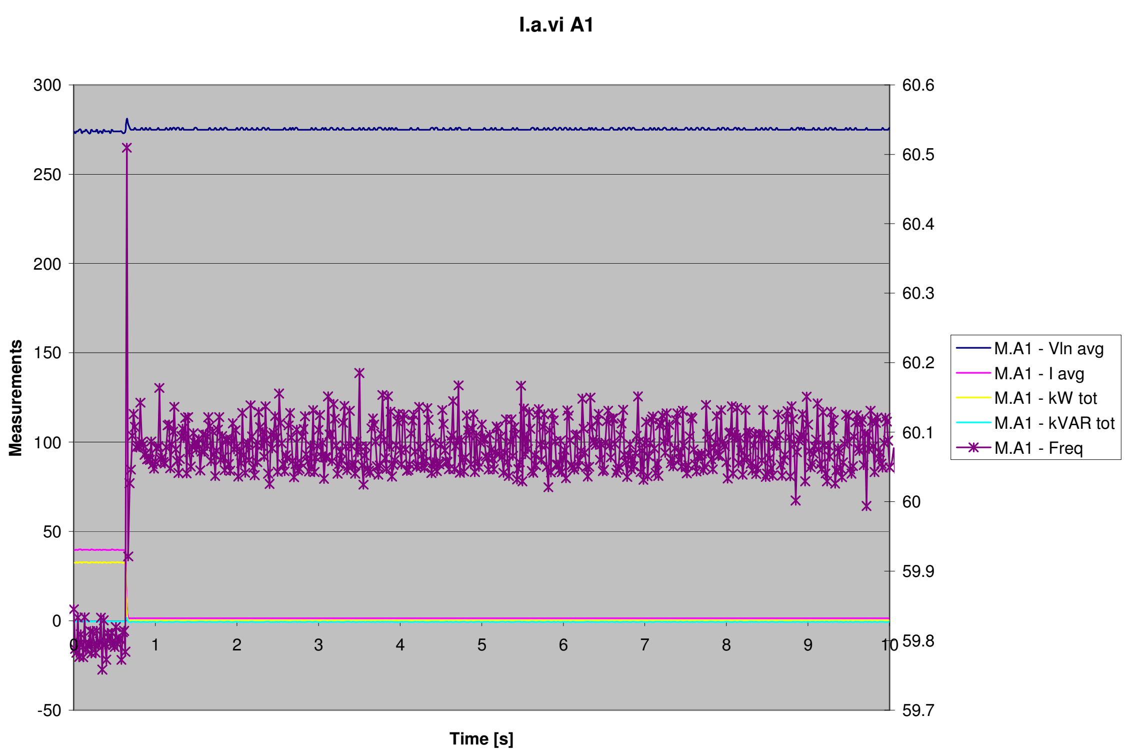
Test I.a.iv A1 = 32.6 – 50.8kW load step



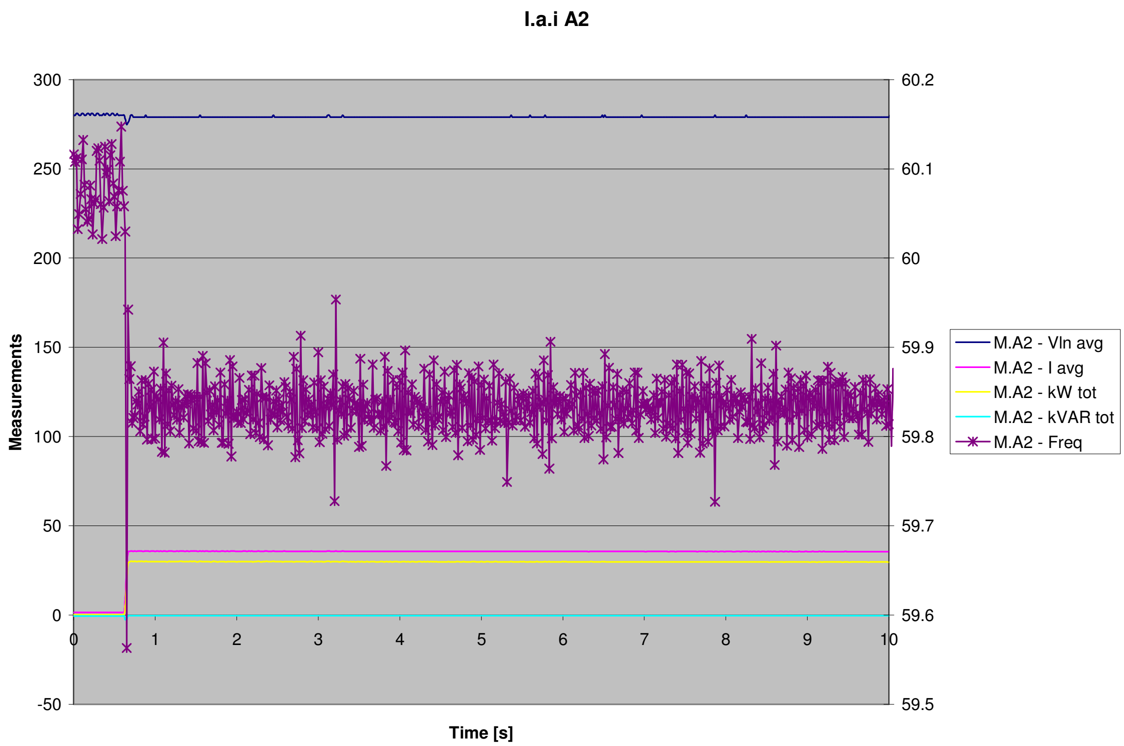
Test I.a.v A1 = 49.5 – 0kW load step



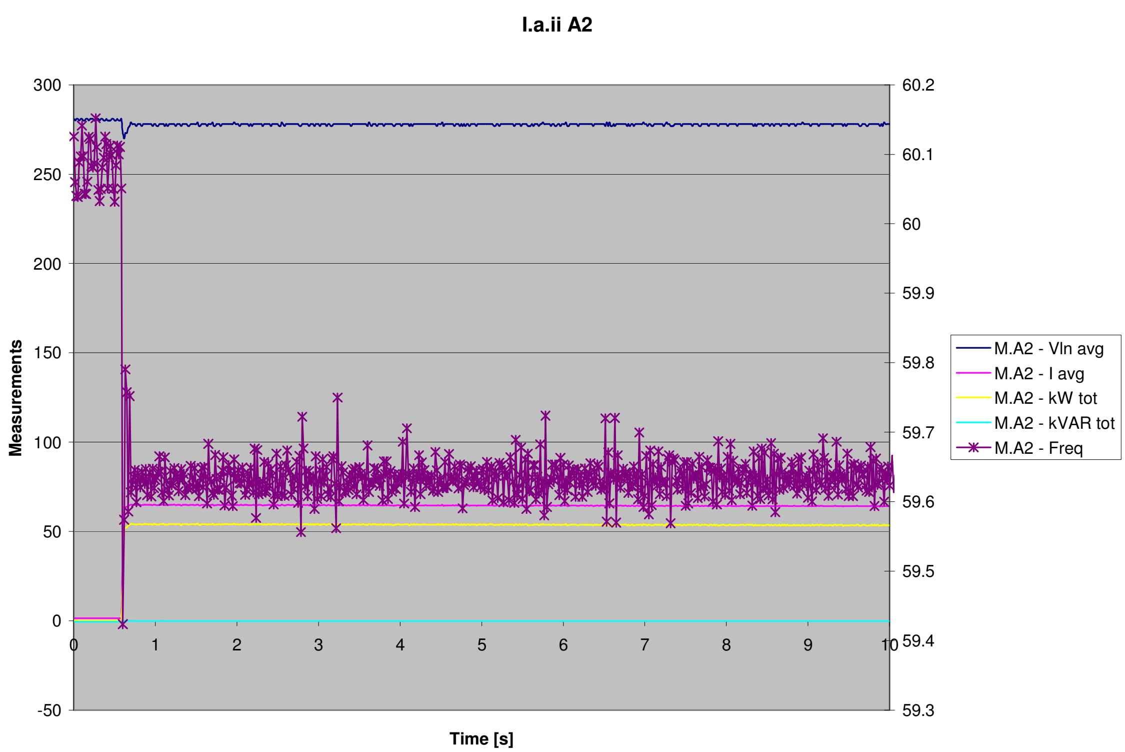
Test I.a.vi A1 = 32.5 – 0kW load step



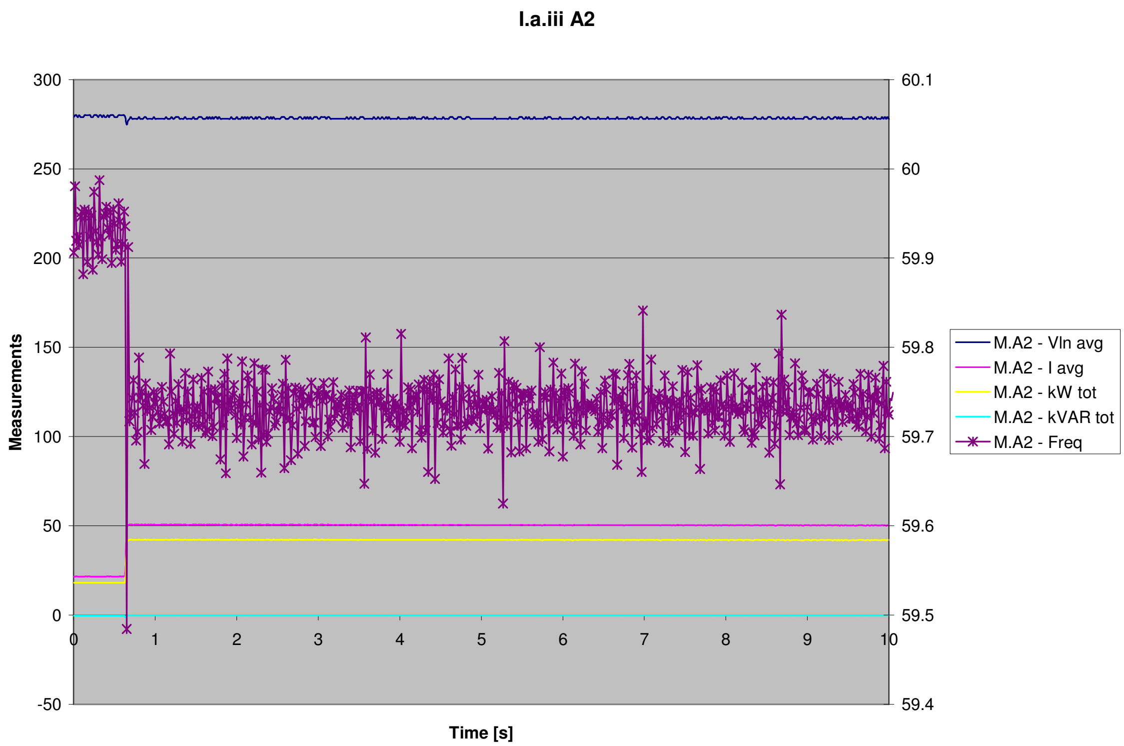
Test I.a.i A2 = 0 – 29.9kW load step



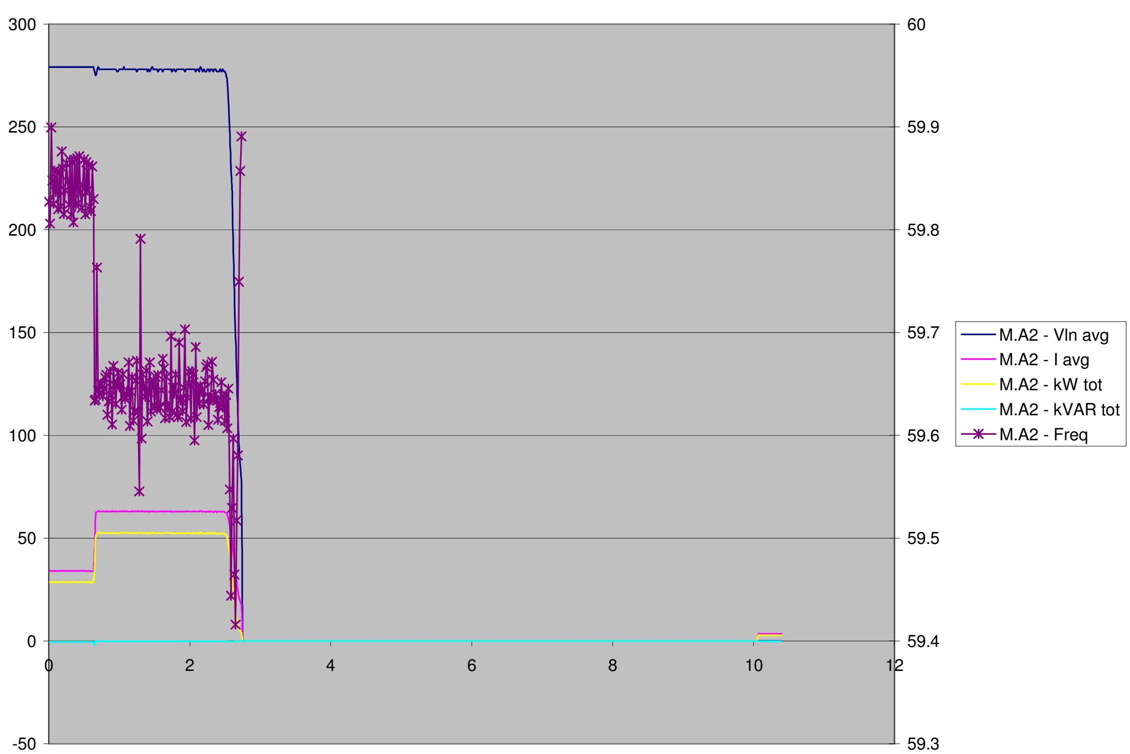
Test I.a.ii A2 = 0 – 53.9kW load step



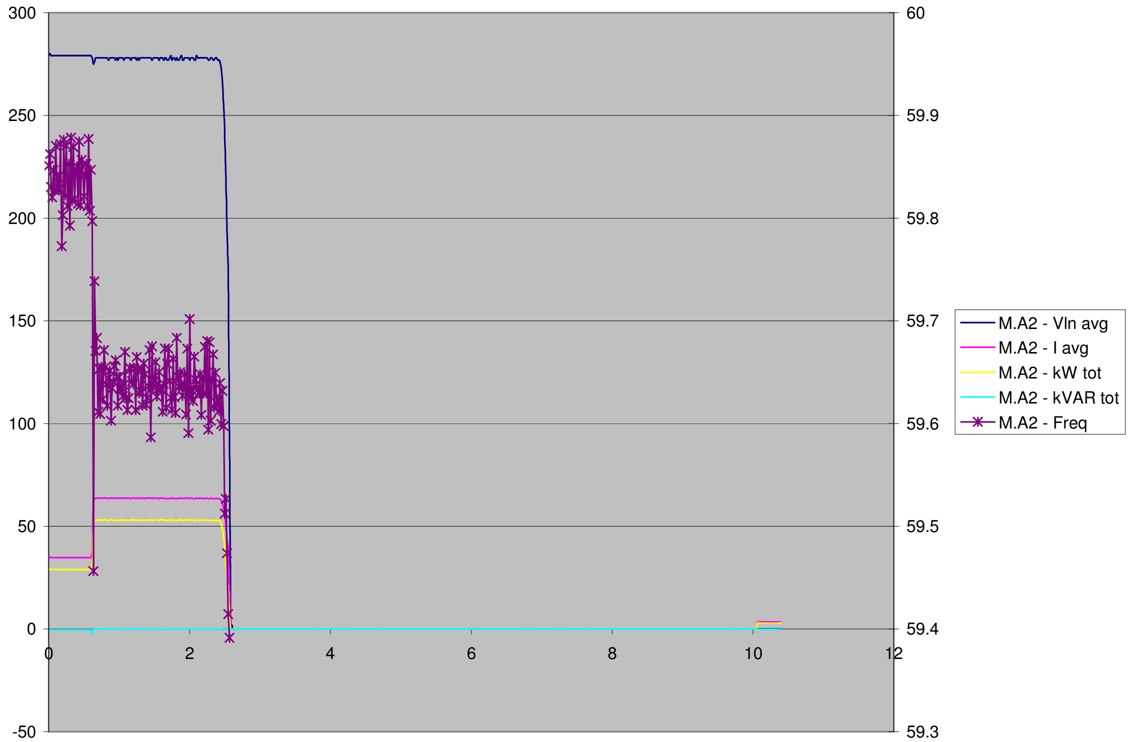
Test I.a.iii A2 = 18 – 42.2kW load step



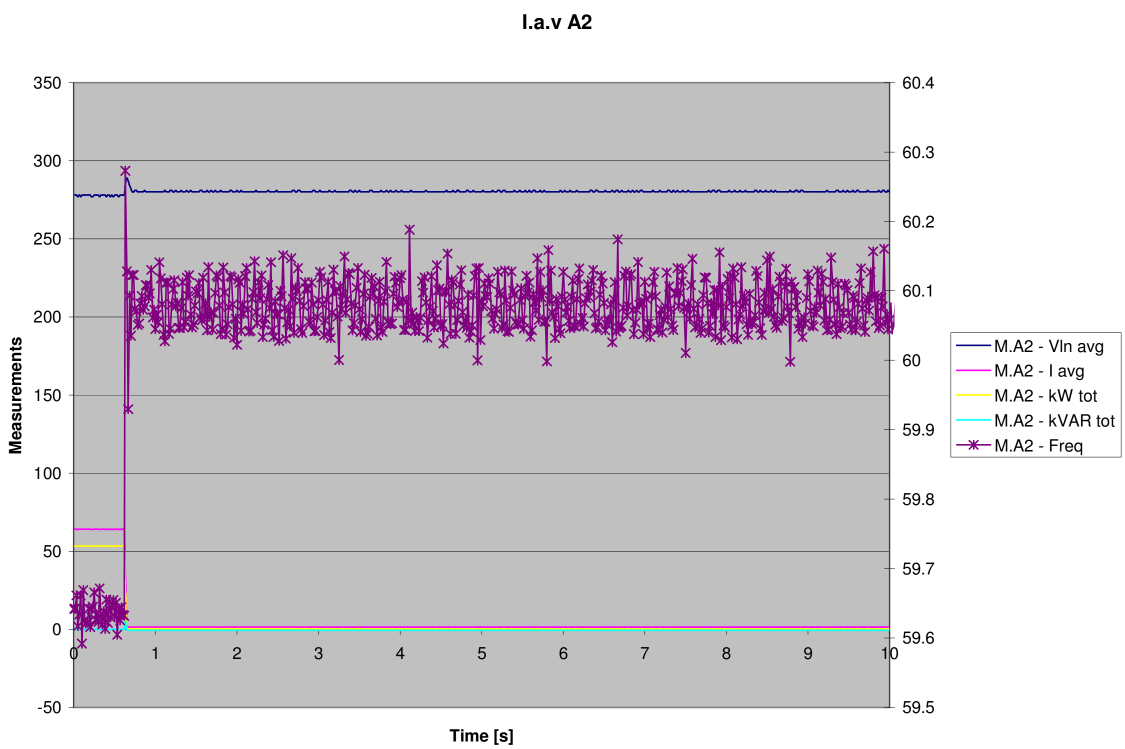
Test I.a.iv A2 = 28.5 – 52.4kW load step, Genset Stalled with No Field Sig



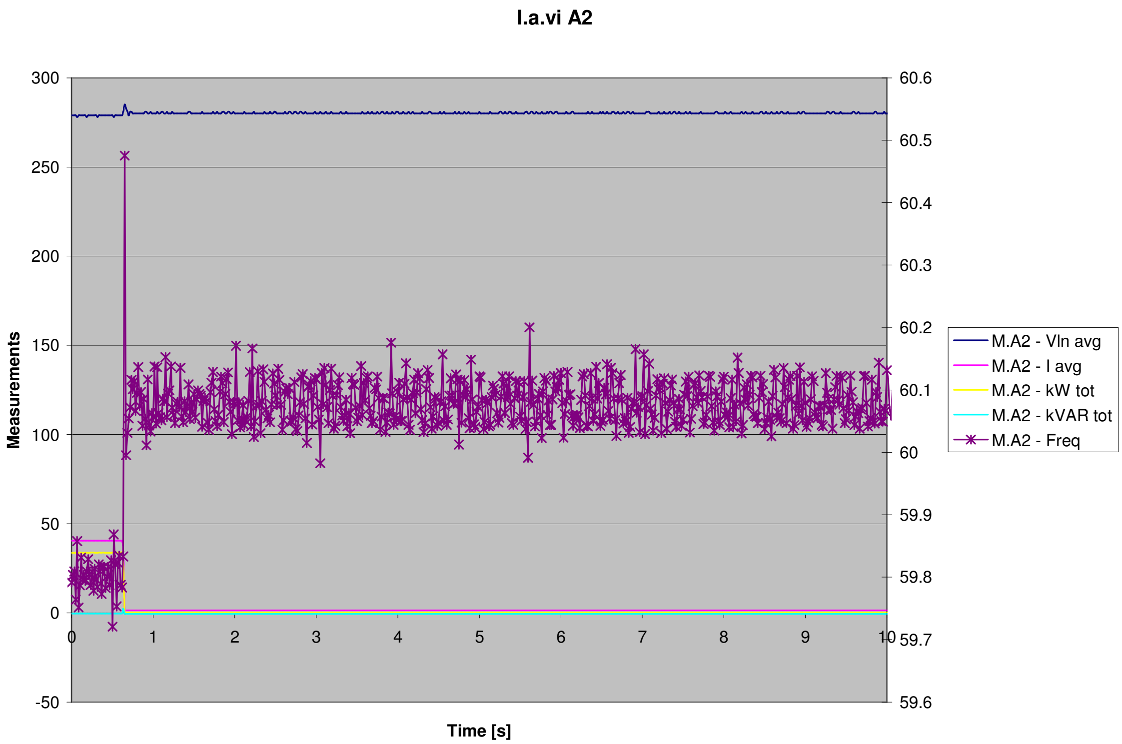
Test I.a.iv A2 = 29 – 51kW load step, Genset Stalled with No Field Sig



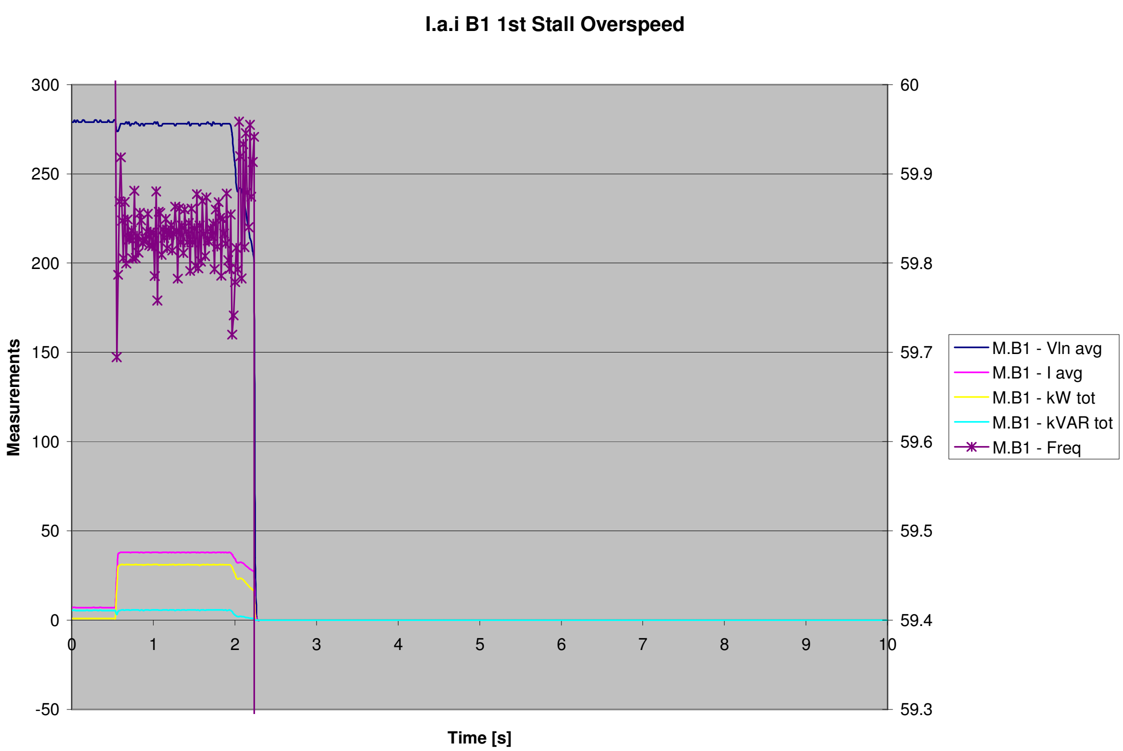
Test I.a.v A2 = 53.5 – 0kW load step



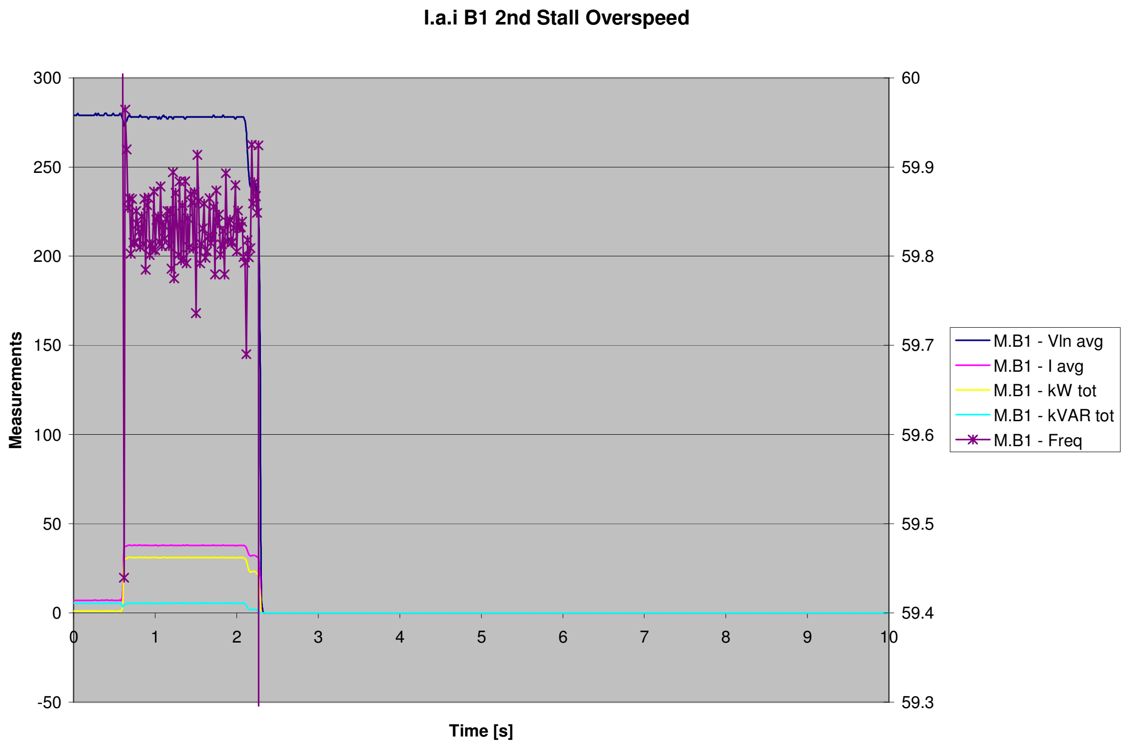
Test I.a.vi A2 = 33.9 – 0kW load step



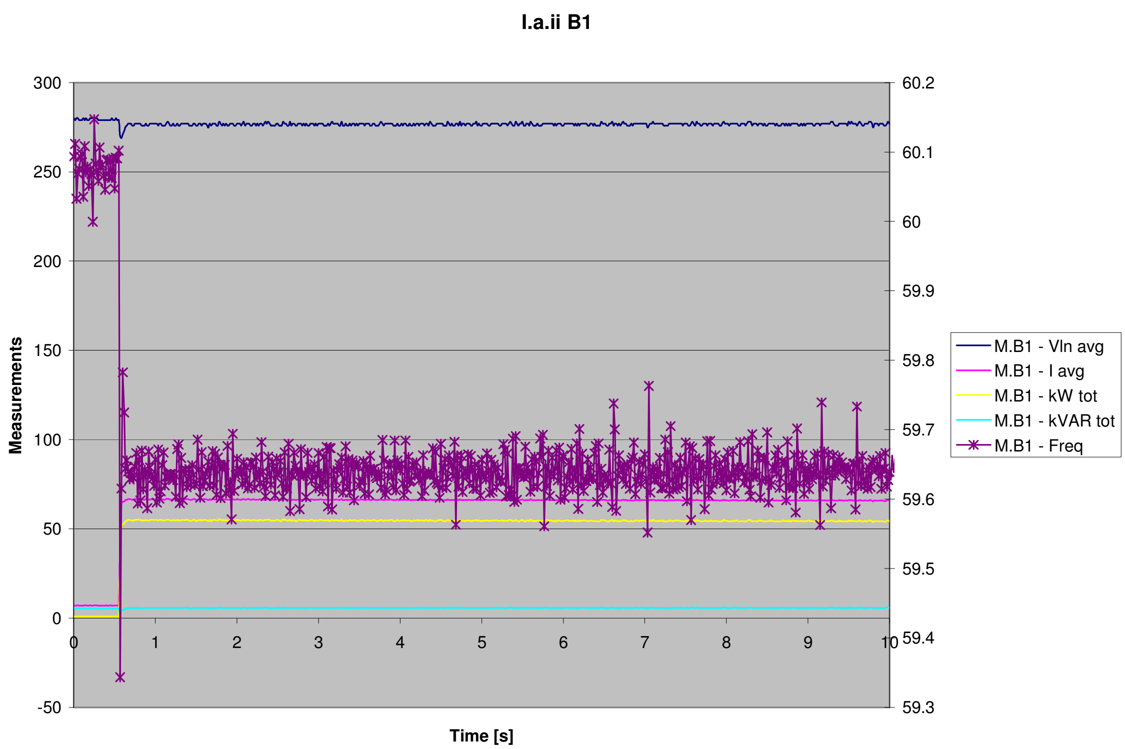
Test I.a.i B1 = 0 – 31kW load step Genset Stalled Overspeed



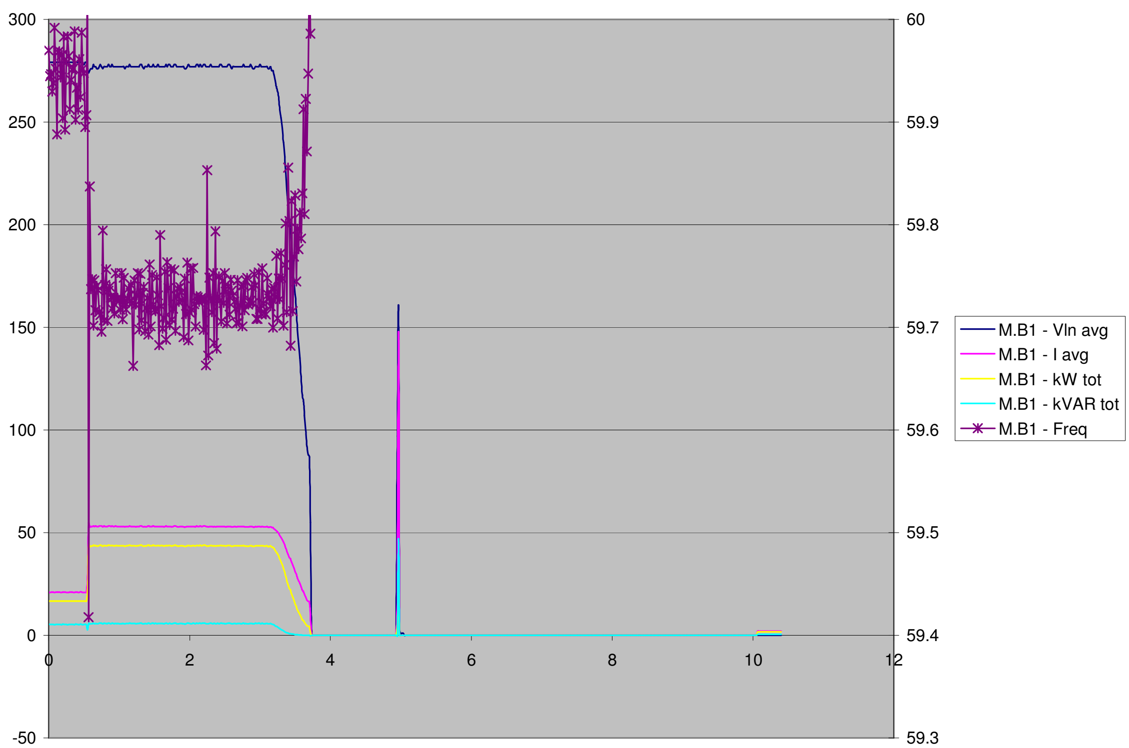
Test I.a.i B1 = 0 – 31kW load step Genset Stalled Overspeed



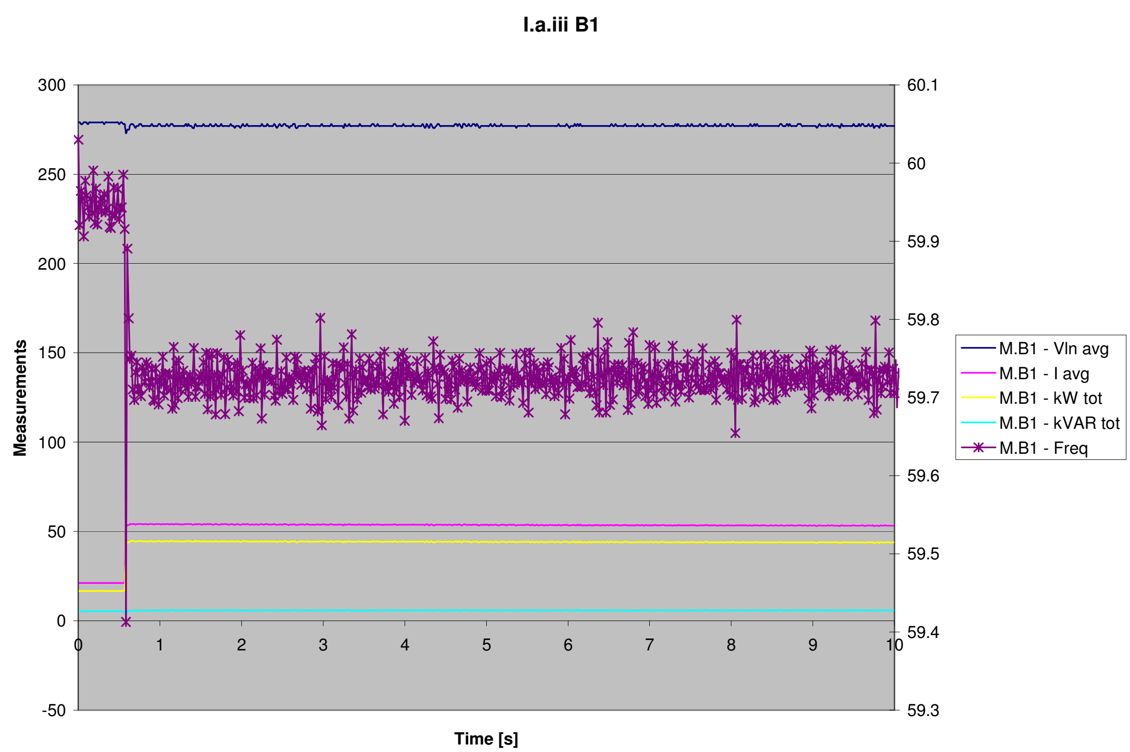
Test I.a.ii B1 = 0 – 54.4kW load step



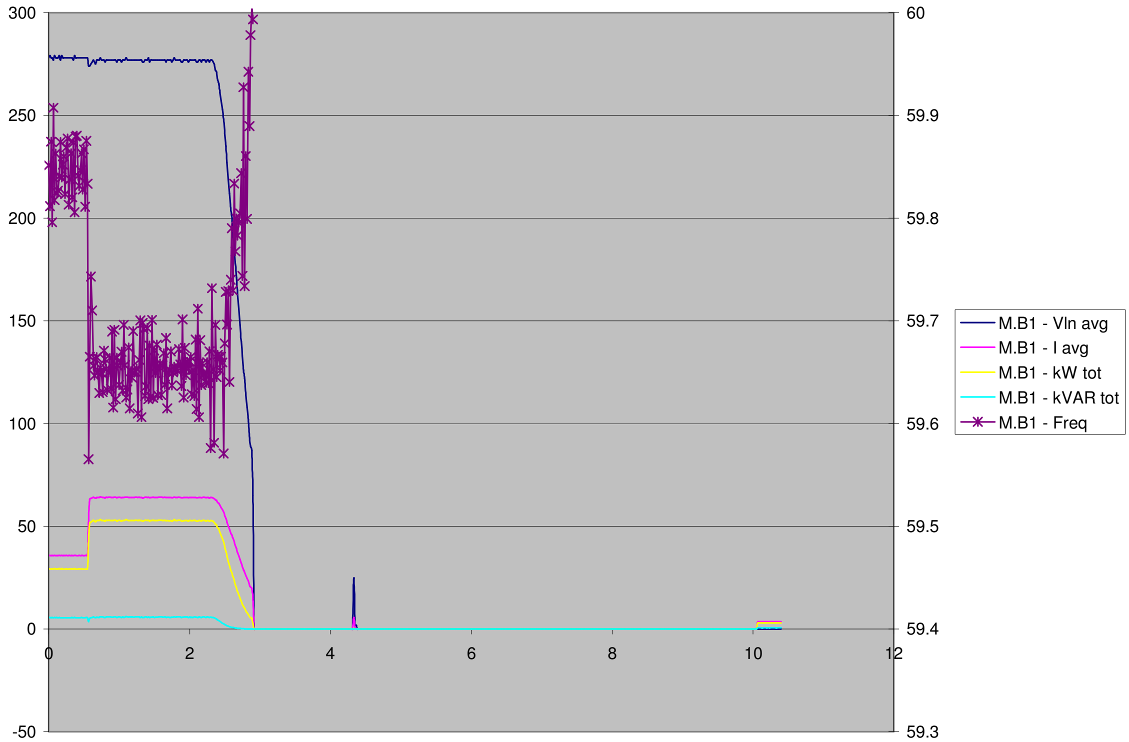
Test I.a.iii B1 = 16.7 – 43.5kW load step Genset Stalled No Field Signal



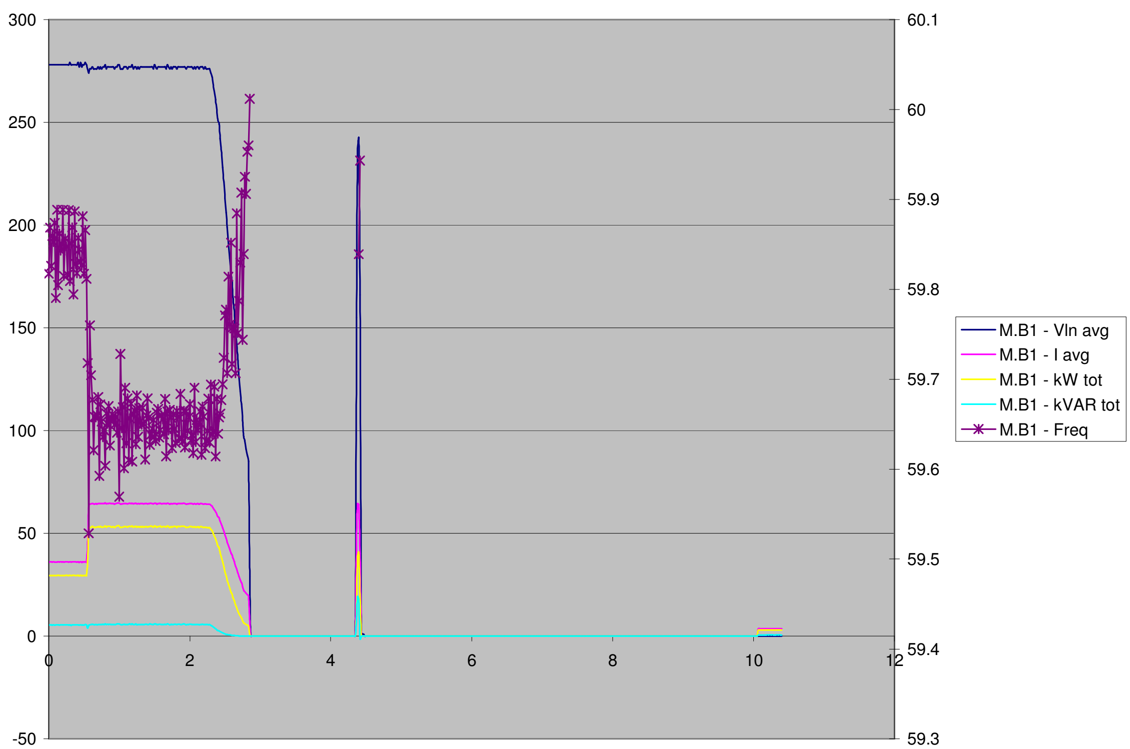
Test I.a.iii B1 = 16.7 – 44.4kW load step



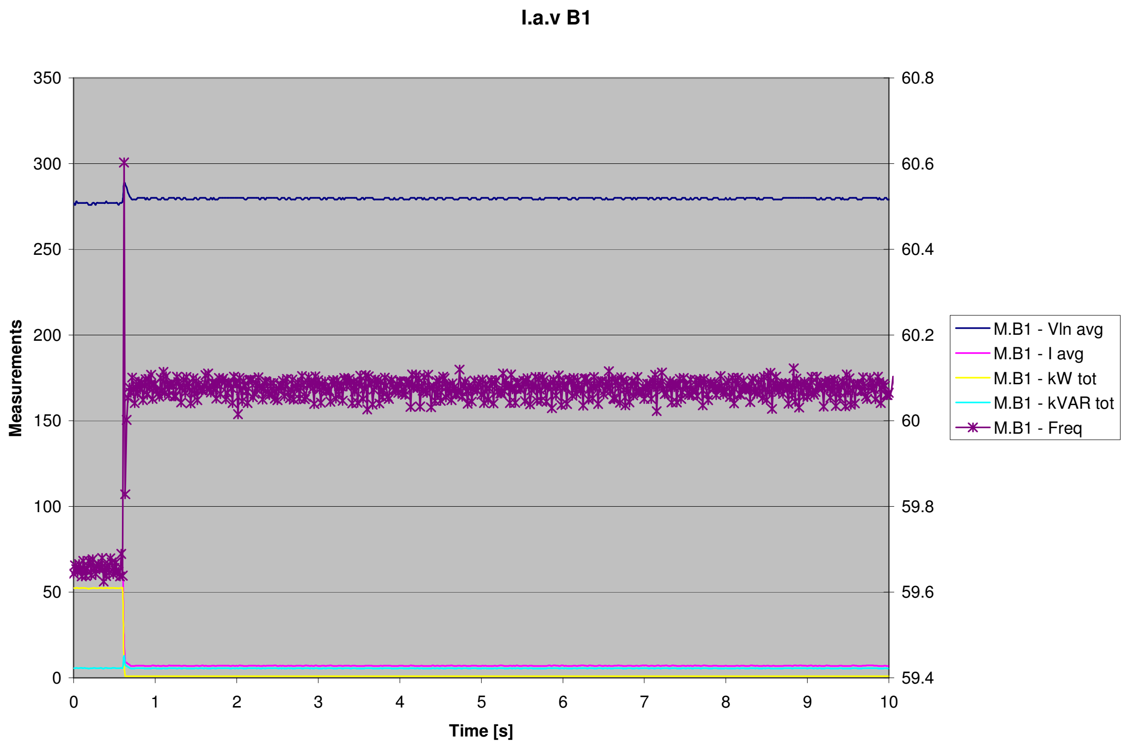
Test I.a.iv B1 = 29.2 – 52.9kW load step No Field Sig



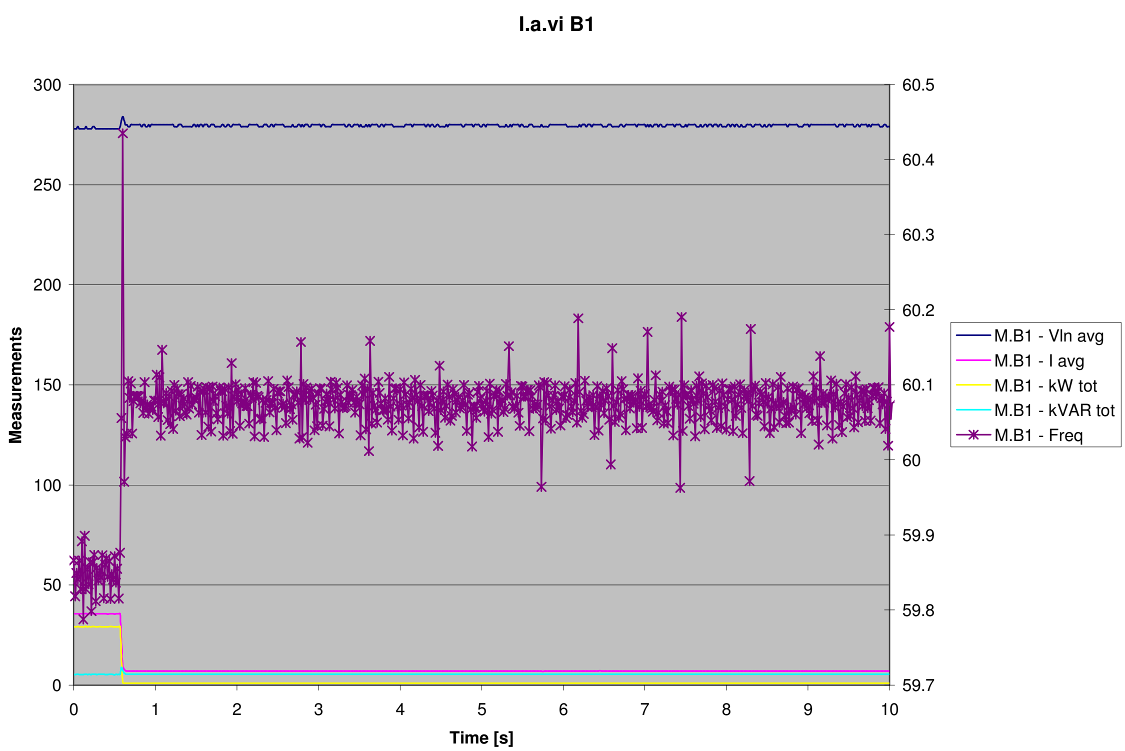
Test I.a.iv B1 = 29.5 – 53.1kW load step No Field Sig



Test I.a.v B1 = 52.2 – 0kW load step



Test I.a.vi B1 = 29.2 – 0kW load step



11. Test Log for 9-20-06

Time	Test	Unit	Load Bank	Load (kW)
Generator B1 with surge module				
1:30 pm	I.a.i	B1	5	0-30
1:33 pm	I.a.ii	B1	5	0-60
1:36 pm	I.a.iii	B1	5	15-50
1:40 pm	I.a.iv	B1	5	30-60
1:43 pm	I.a.v	B1	5	60-0
1:46 pm	I.a.vi	B1	5	30-0
Generator A1 w/out surge module				
1:55 pm	II.c.i (Part 1)	A1	4	50
1:57 pm	A1 Shutdown	A1	4	50
Generator A1and A2 with surge module(s)				
2:01 pm	II.c.i (Part 1)	A1	4	50

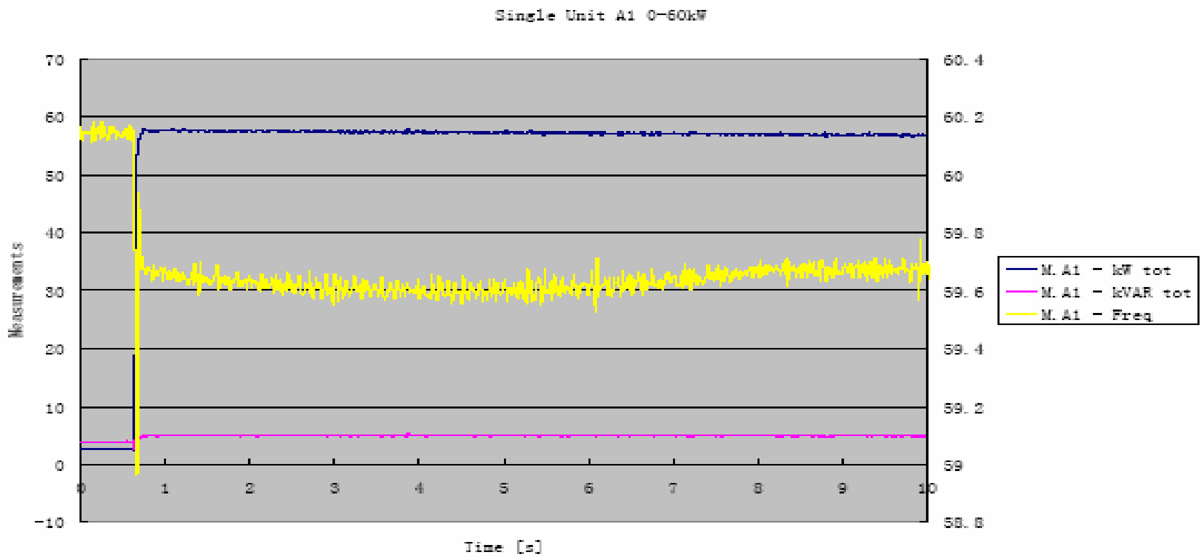
12. Test Log for 9-21-06

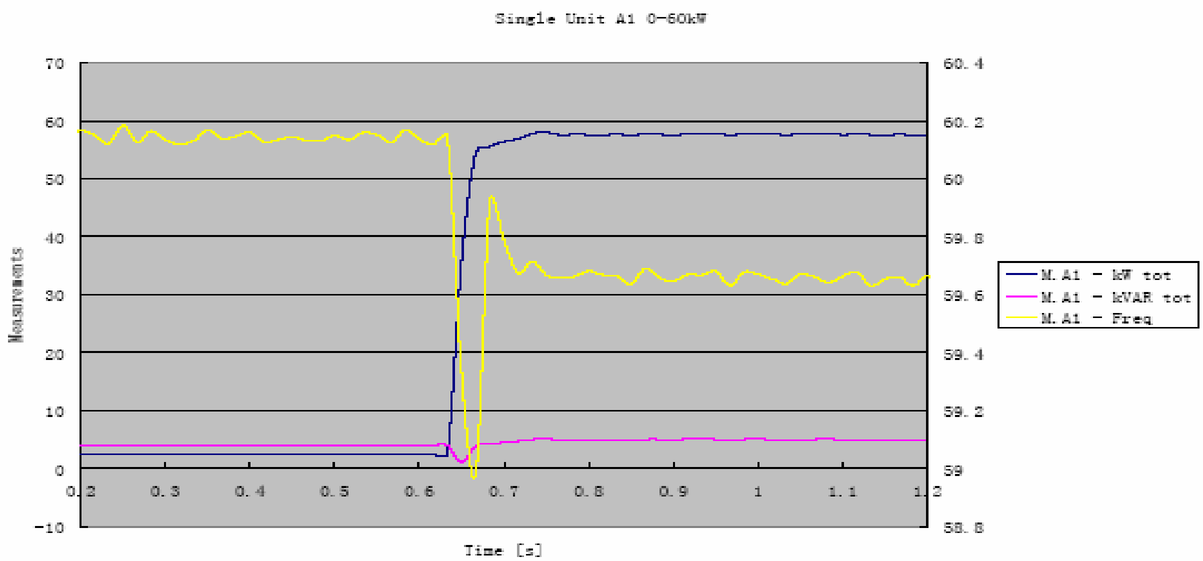
Time	Test	Unit	Load Bank	Load (kW)
Generator A1 with surge module				
7:49 am	I.a.i	A1	3	0-30
8:00 am	I.a.ii	A1	3	0-60
8:03 am	I.a.iii	A1	3	15-50
8:19 am	I.a.iv	A1	3	30-60
8:22 am	I.a.v	A1	3	60-0
8:25 am	I.a.vi	A1	3	30-0
Generator A2 with surge module				
10:18 am	Trigger Test			
10:21 am	I.a.i	A2	4	0-30
10:24 am	I.a.ii	A2	4	0-60
10:28 am	I.a.iii	A2	4	15-50
10:31 am	I.a.iv	A2	4	30-60
10:34 am	I.a.v	A2	4	60-0
10:37 am	I.a.vi	A2	4	30-0

Attachment 13

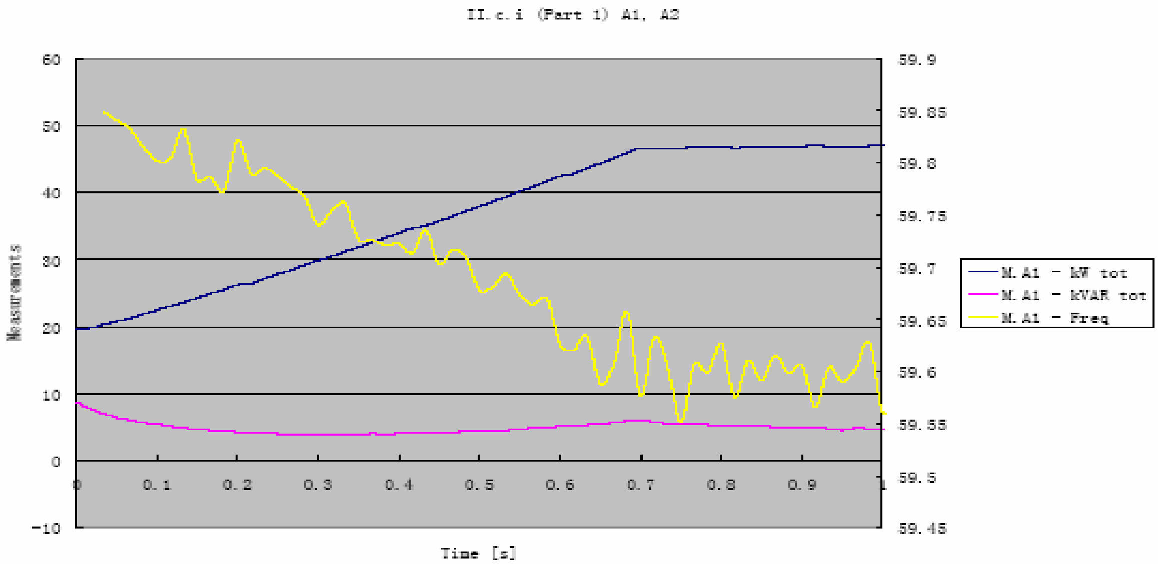
Test Results for 10-11-06

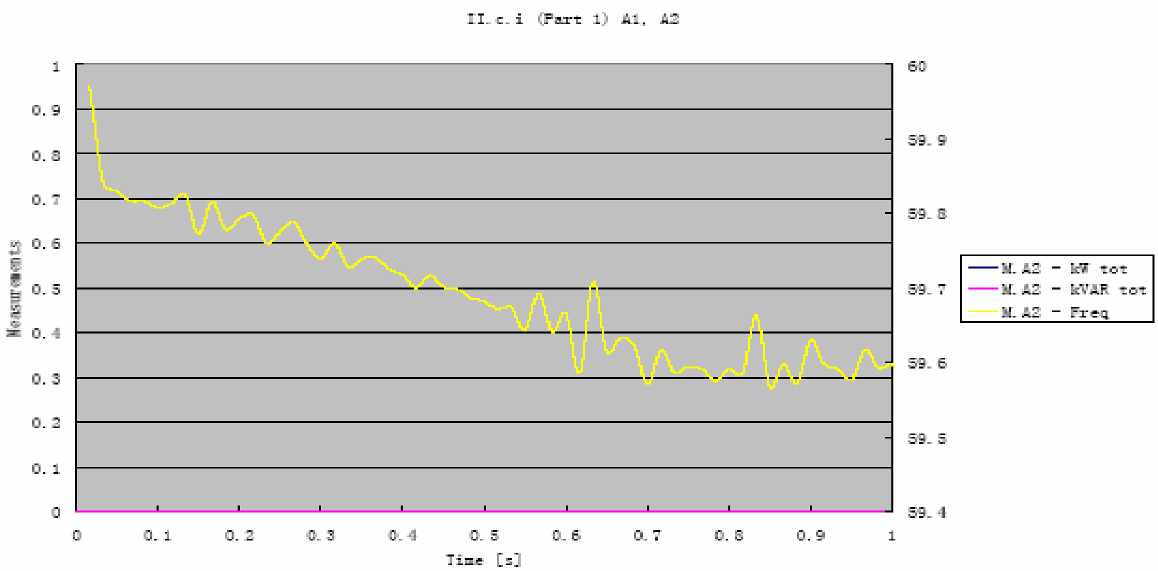
Unit A1, case I.a.ii

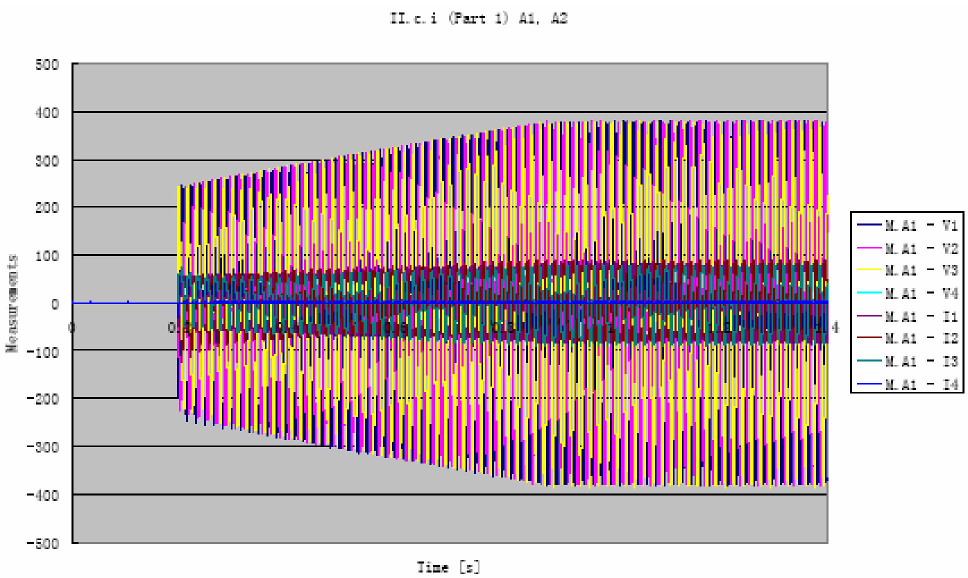


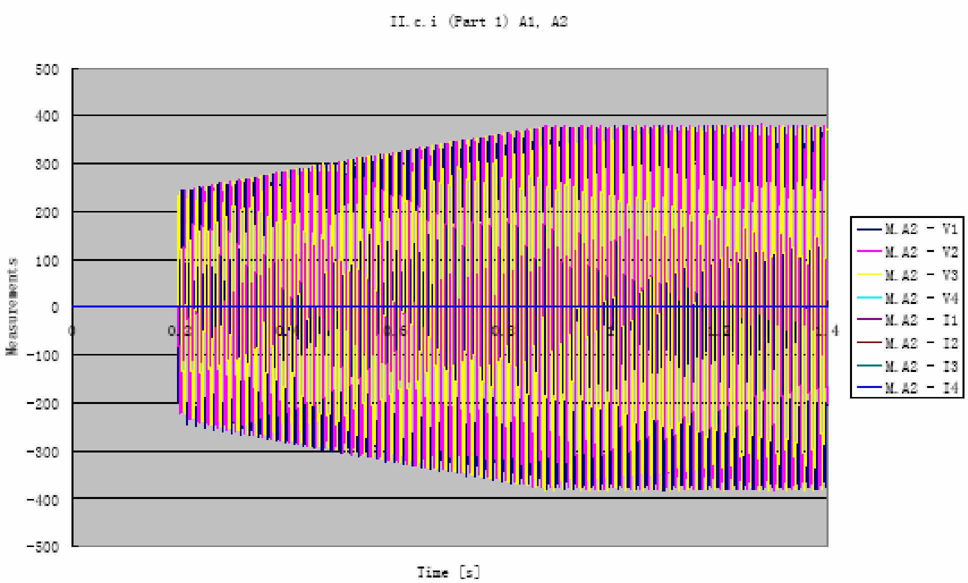


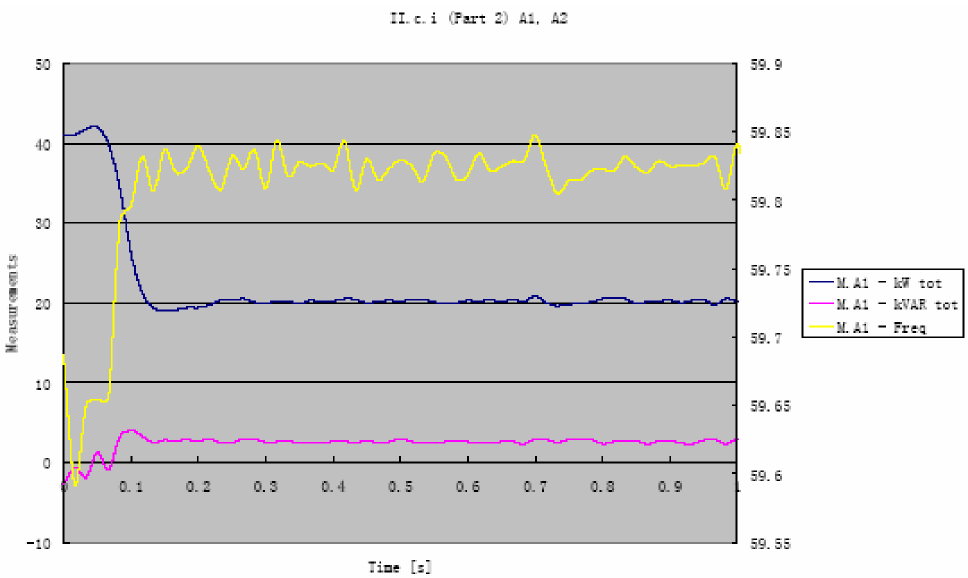
II.c.i with units A1 and A2

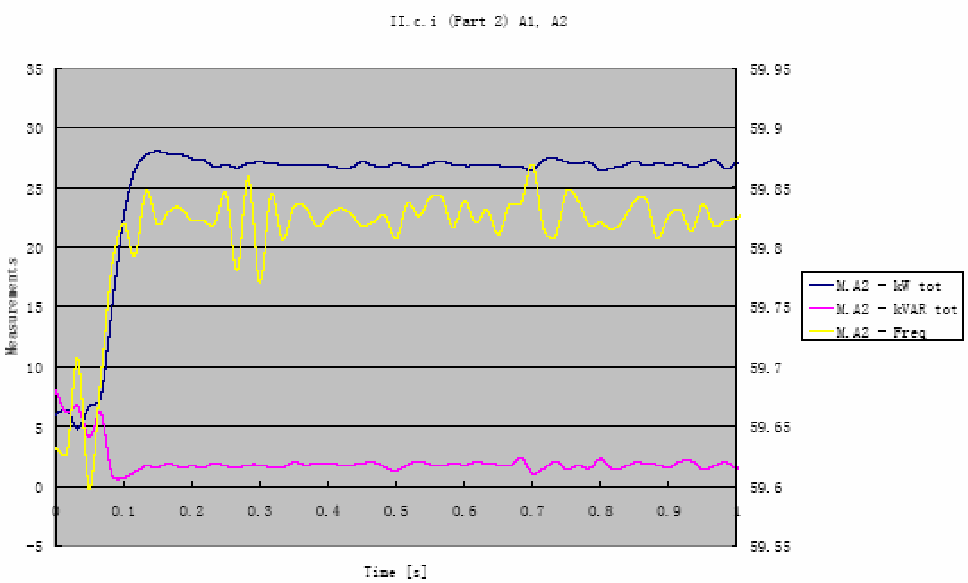


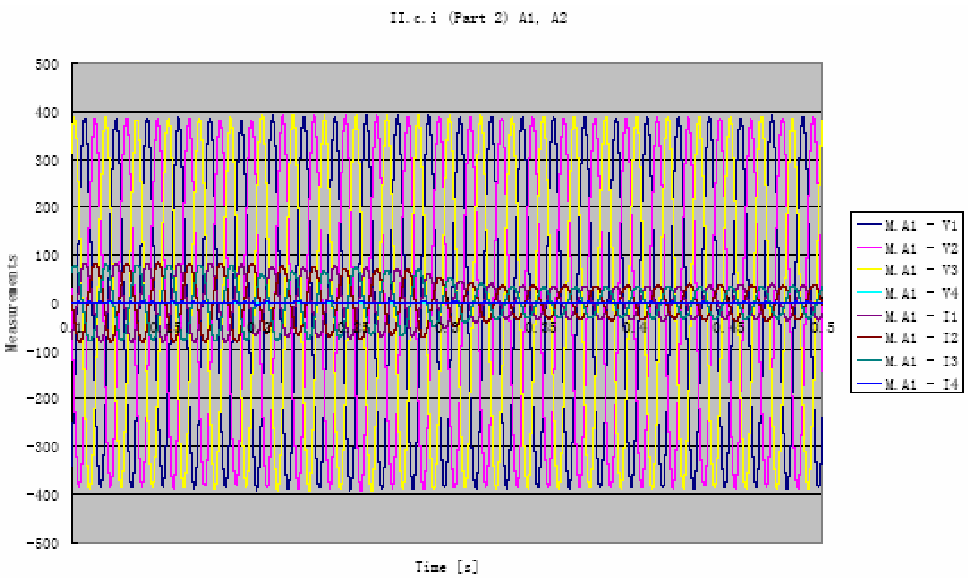


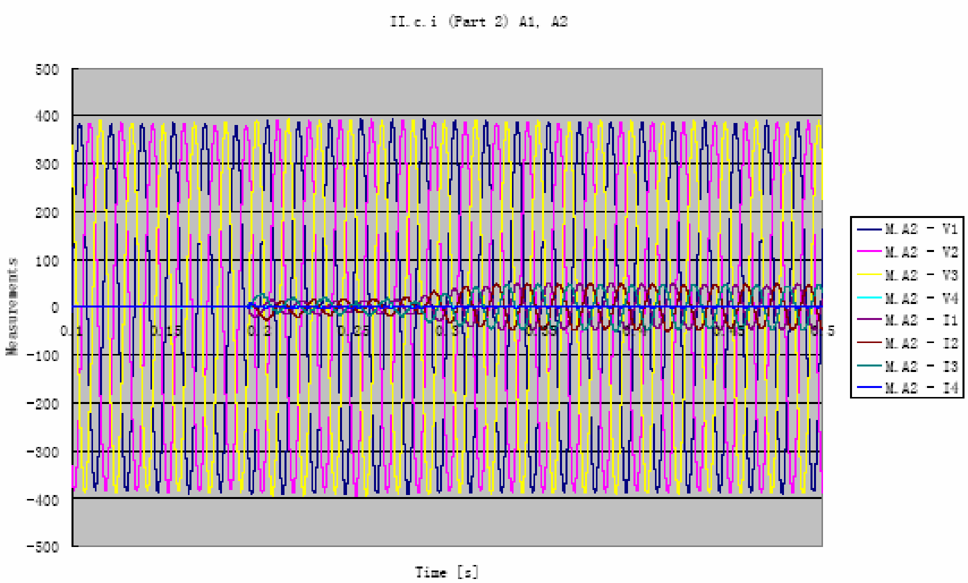

II.c.i (Part 1) A1, A2
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4

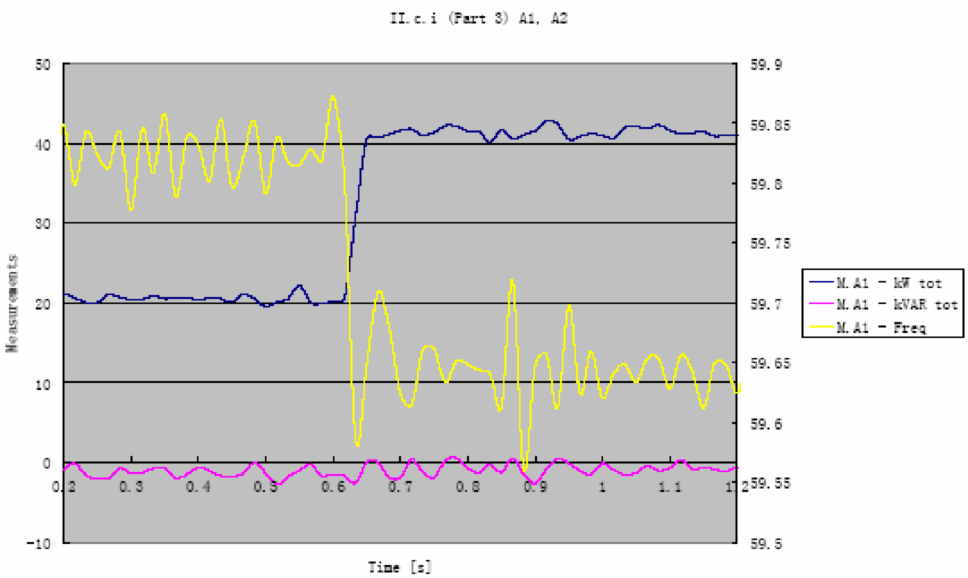

II.c.i (Part 1) A1, A2
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

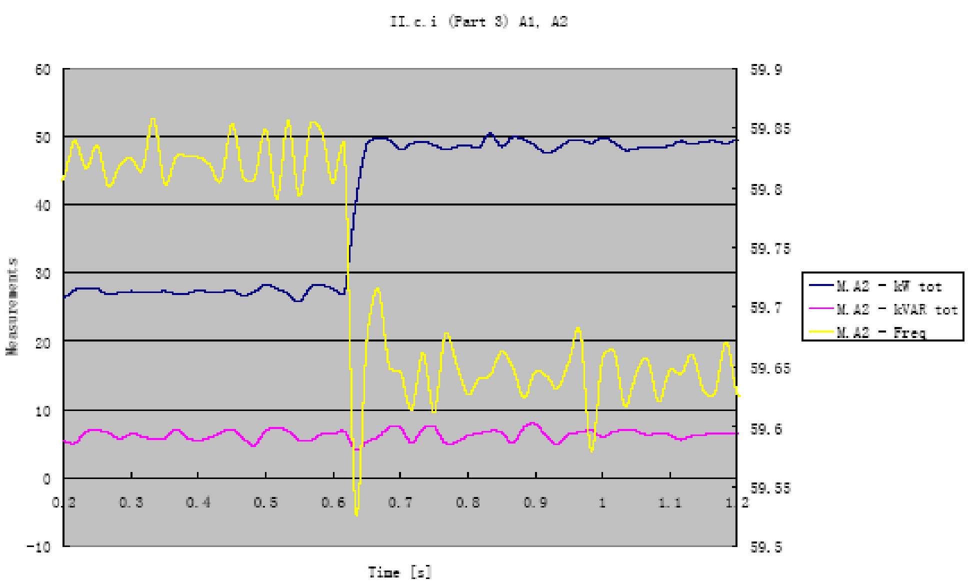

II.c.i (Part 2) A1, A2
Measurements
Time [s]
M.A1 - kW tot
M.A1 - kVAR tot
M.A1 - Freq

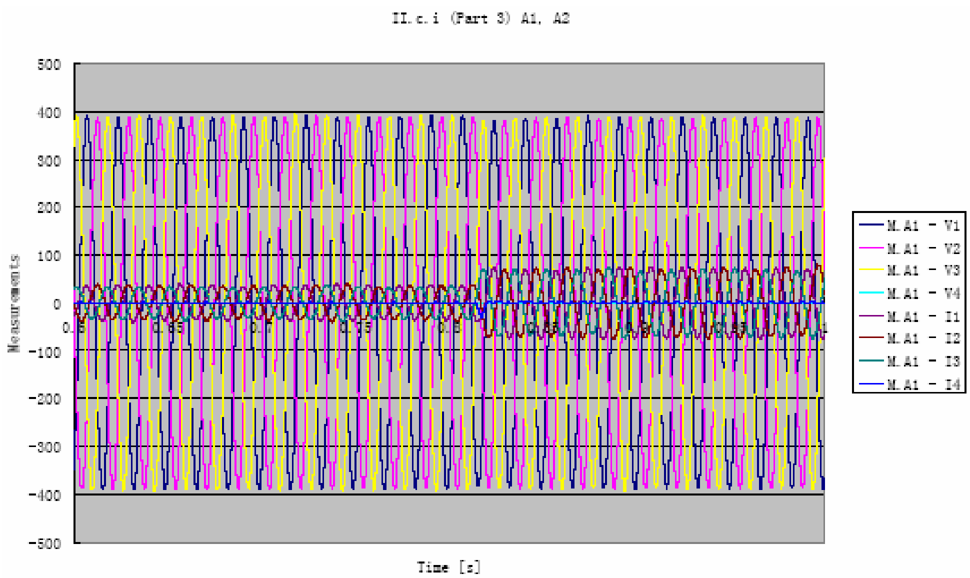

II.c.i (Part 2) A1, A2
Measurements
Time [s]
M.A2 - kW tot
M.A2 - kVAR tot
M.A2 - Freq


II.c.i (Part 2) A1, A2
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4

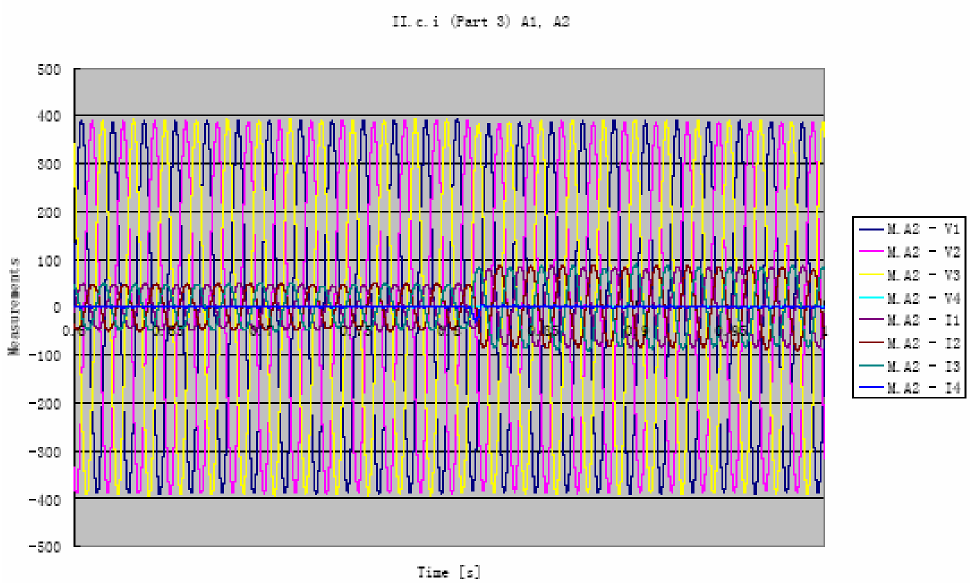

II.c.i (Part 2) A1, A2
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4


II.c.i (Part 3) A1, A2
Measurements
Time [s]
M.A1 - kW tot
M.A1 - kVAR tot
M.A1 - Freq


II.c.i (Part 3) A1, A2
Measurements
Time [s]
M.A2 - kW tot
M.A2 - kVAR tot
M.A2 - Freq

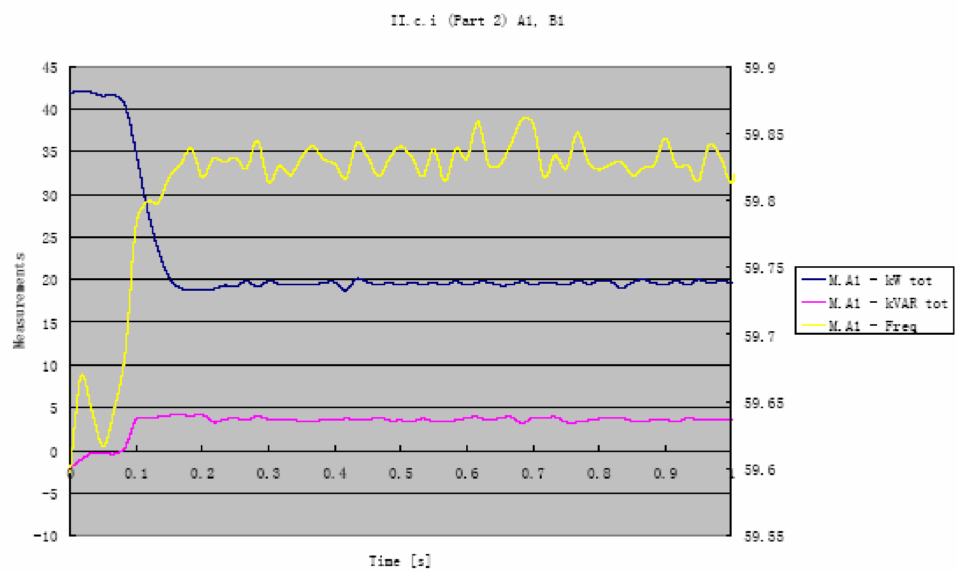


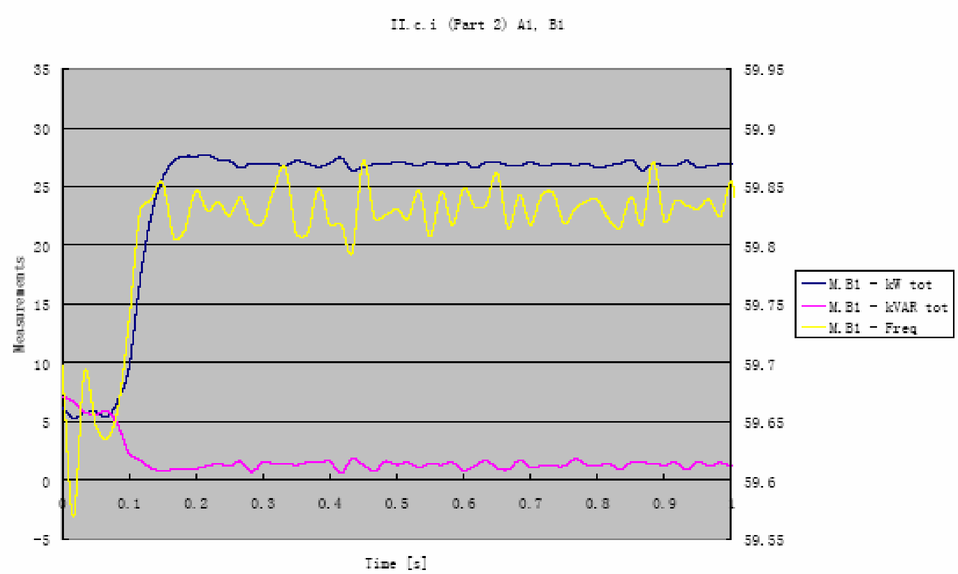
II.c.i (Part 3) A1, A2
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4



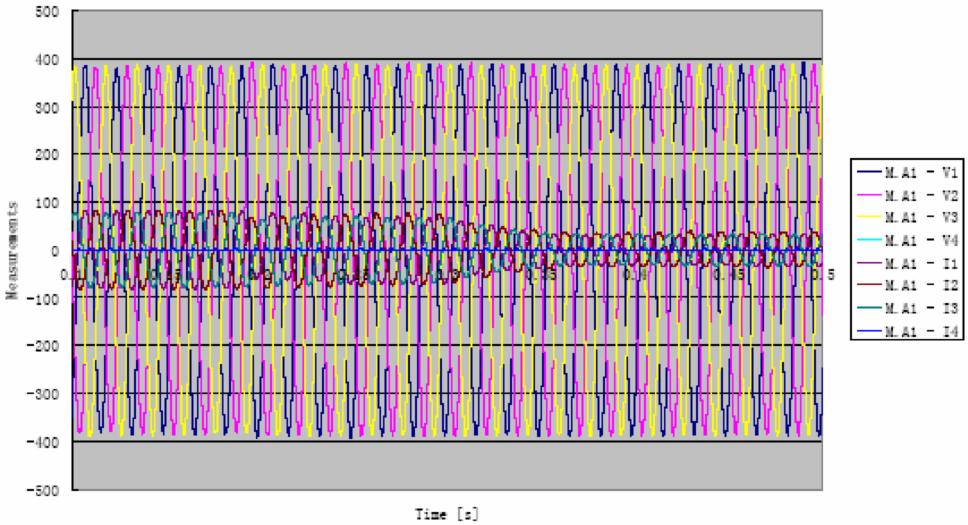
II.c.i (Part 3) A1, A2
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.c.i with units A1 and B1

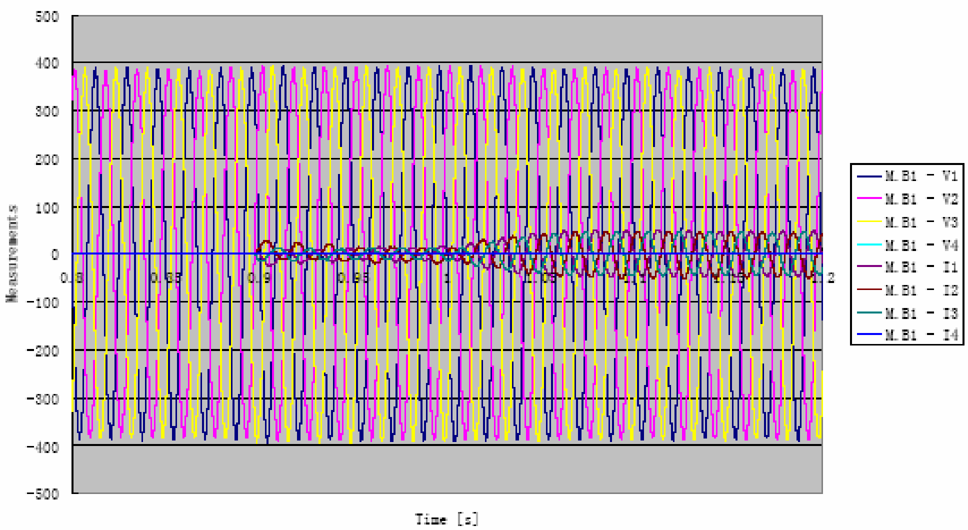


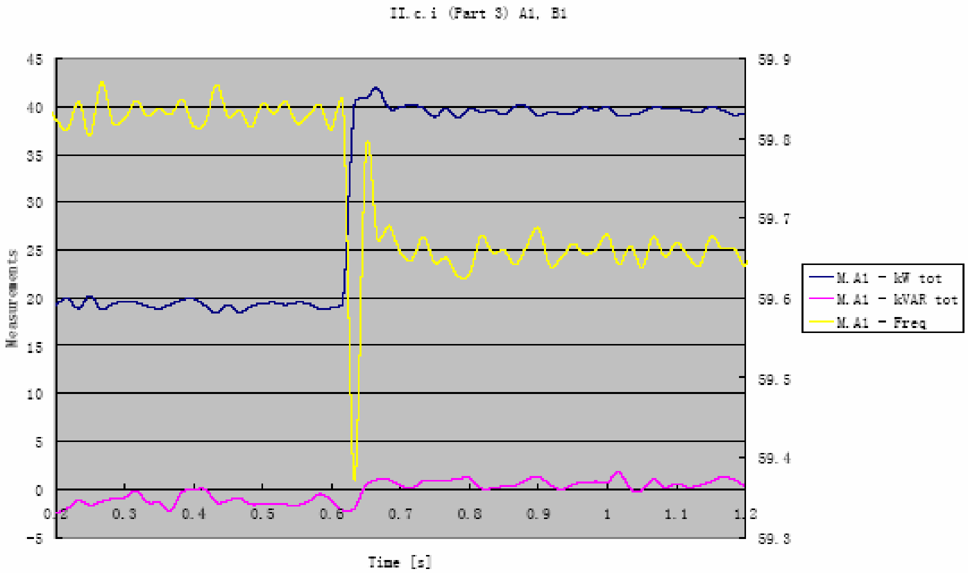


II.c.i (Part 2) A1, B1

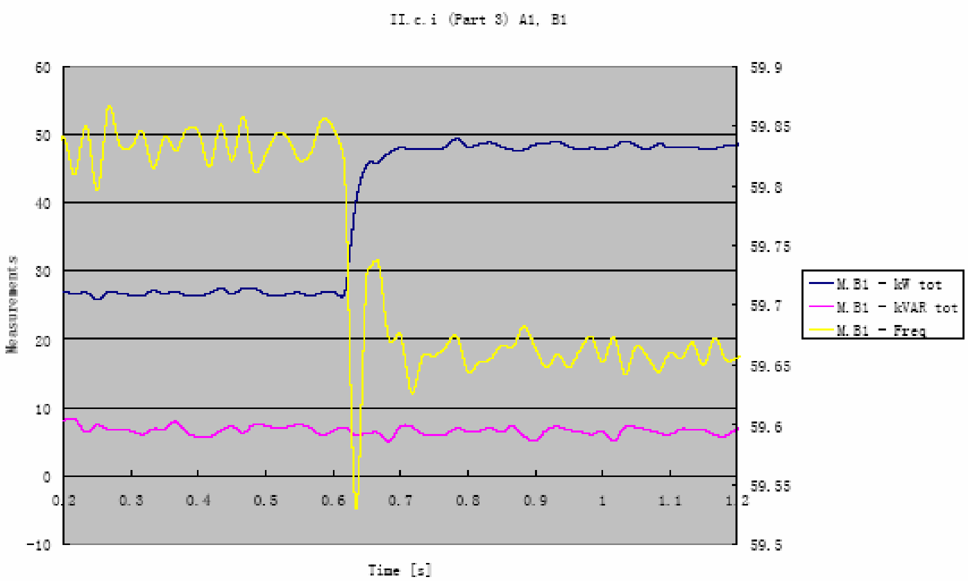


II.c.i (Part 2) A1, B1

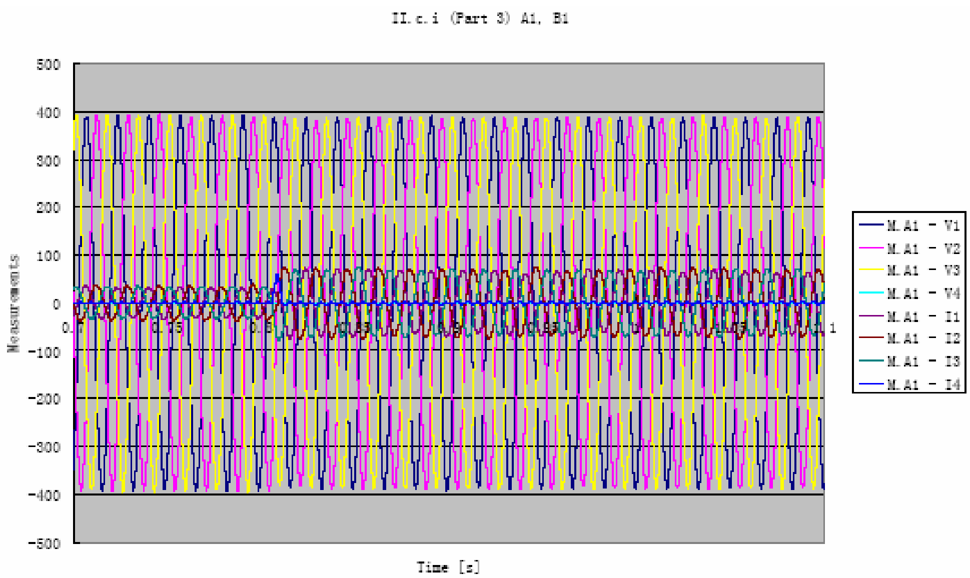




II.c.i (Part 3) A1, B1
Measurements
Time [s]
M.A1 - kW tot
M.A1 - kVAR tot
M.A1 - Freq

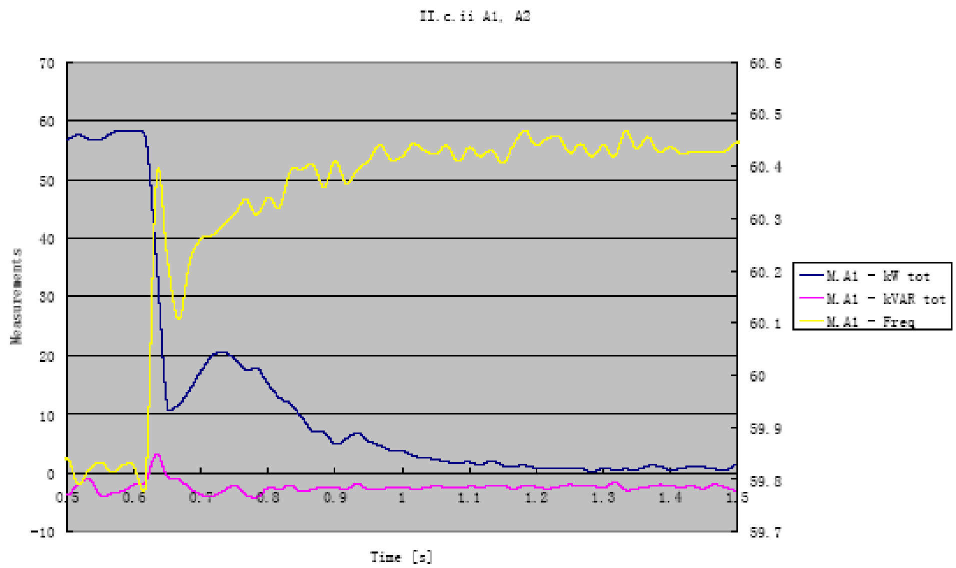


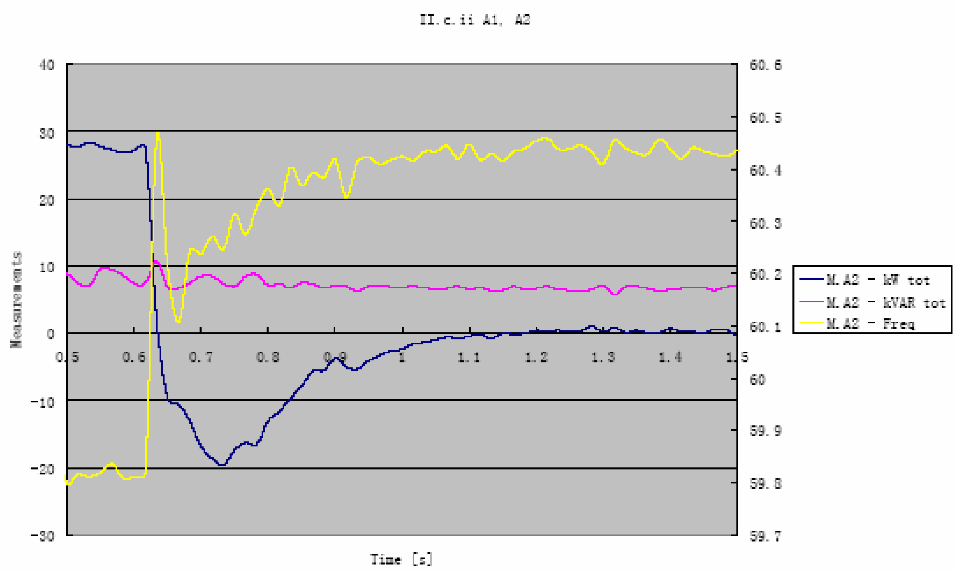
II.c.i (Part 3) A1, B1
Measurements
Time [s]
M.B1 - kW tot
M.B1 - kVAR tot
M.B1 - Freq

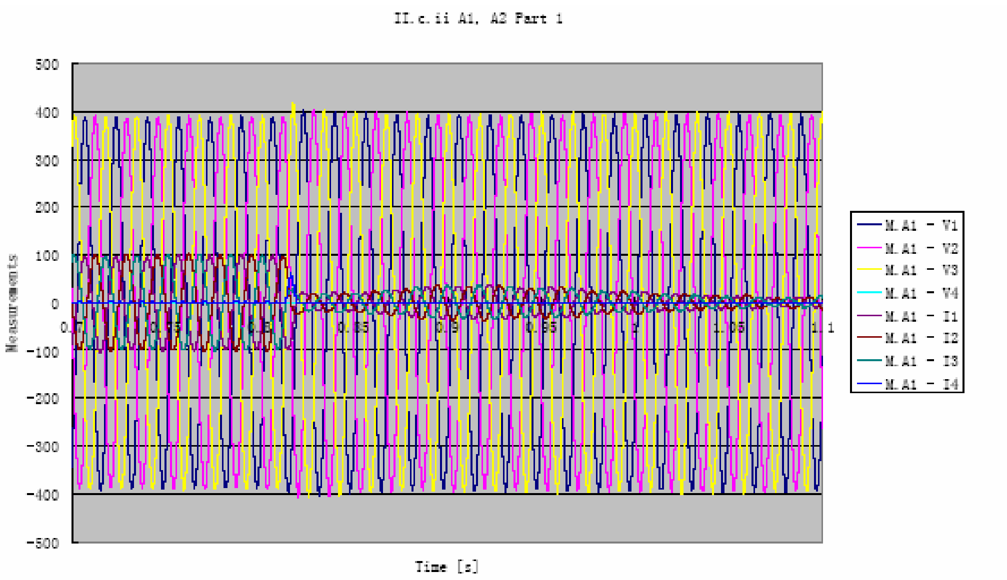


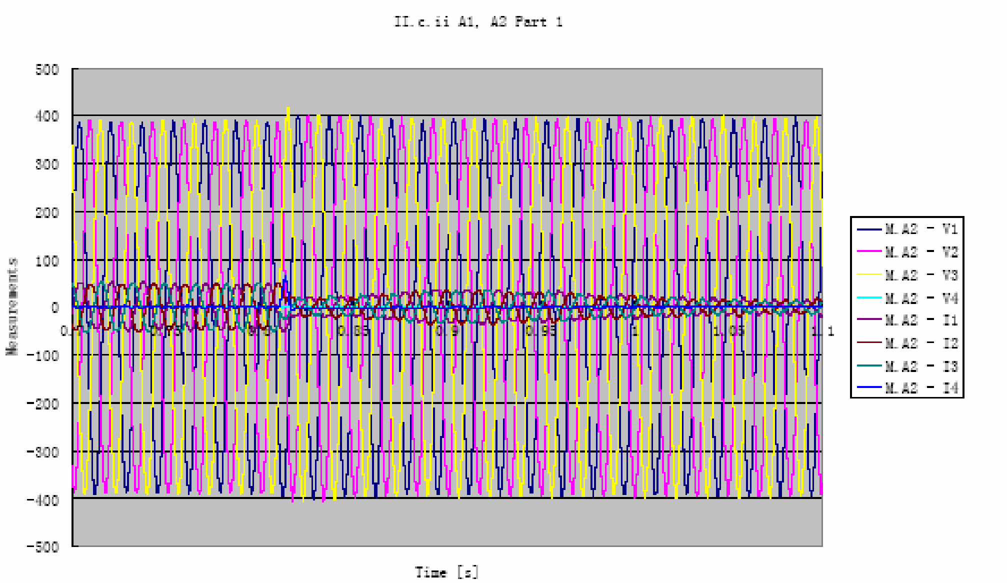
Event non captured

II.c.ii with units A1 and A2

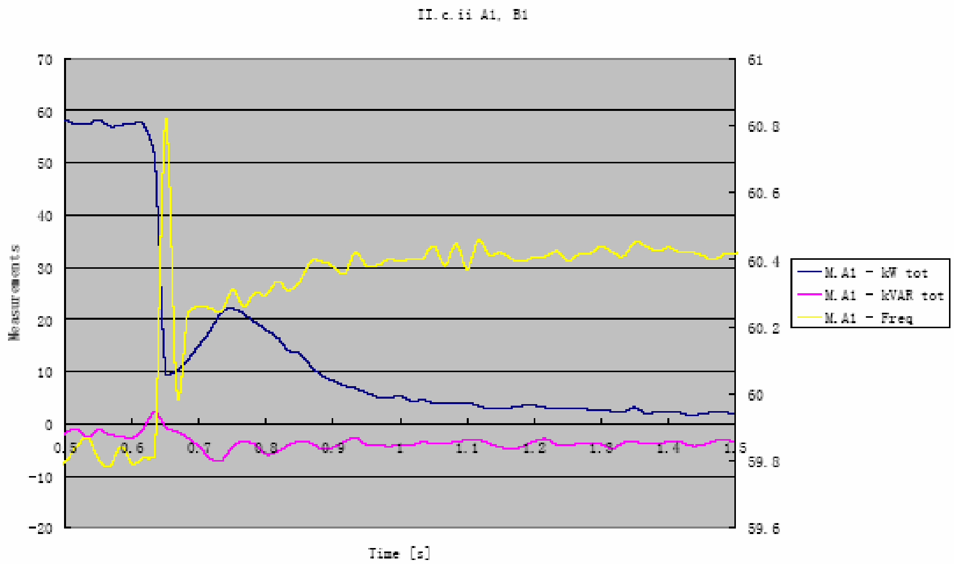


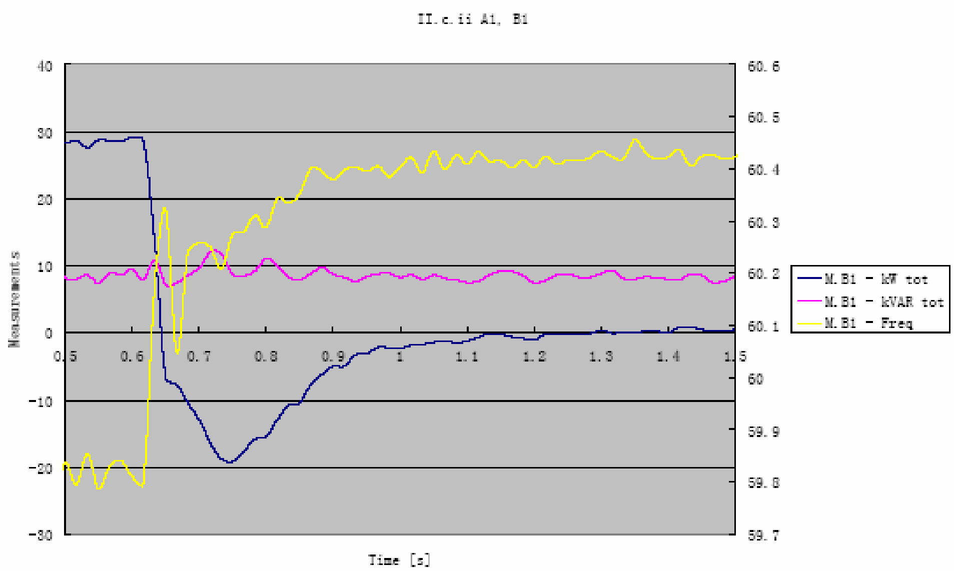


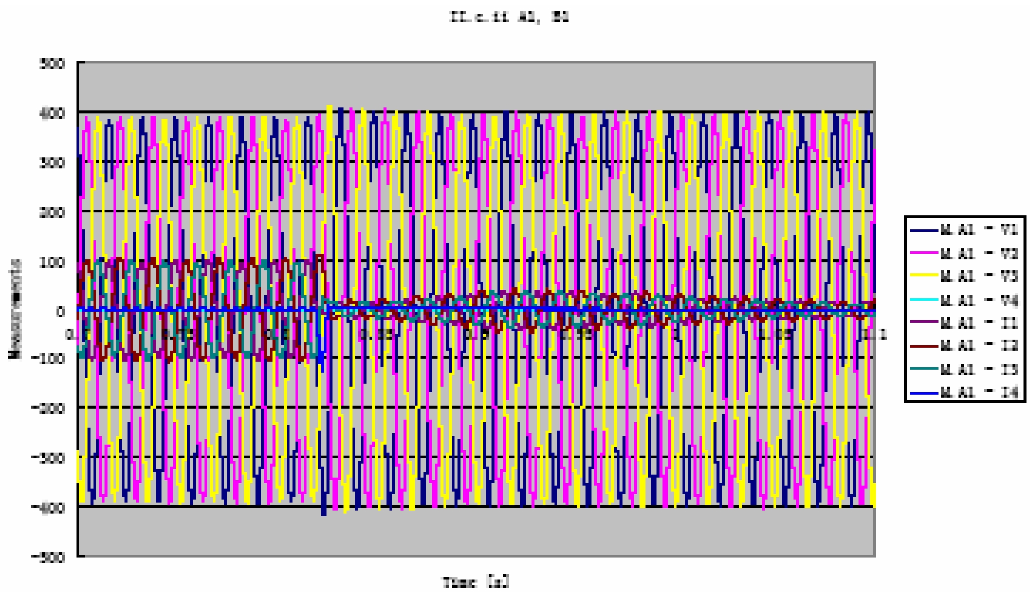

II.c.ii A1, A2 Part 1
500
400
300
200
100
0
-100
-200
-300
-400
-500
0.85
0.9
0.95
1
1.05
1.1
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4


II.c.ii A1, A2 Part 1
500
400
300
200
100
0
-100
-200
-300
-400
-500
0.85
0.9
0.95
1
1.05
1.1
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.c.ii with units A1 and B1

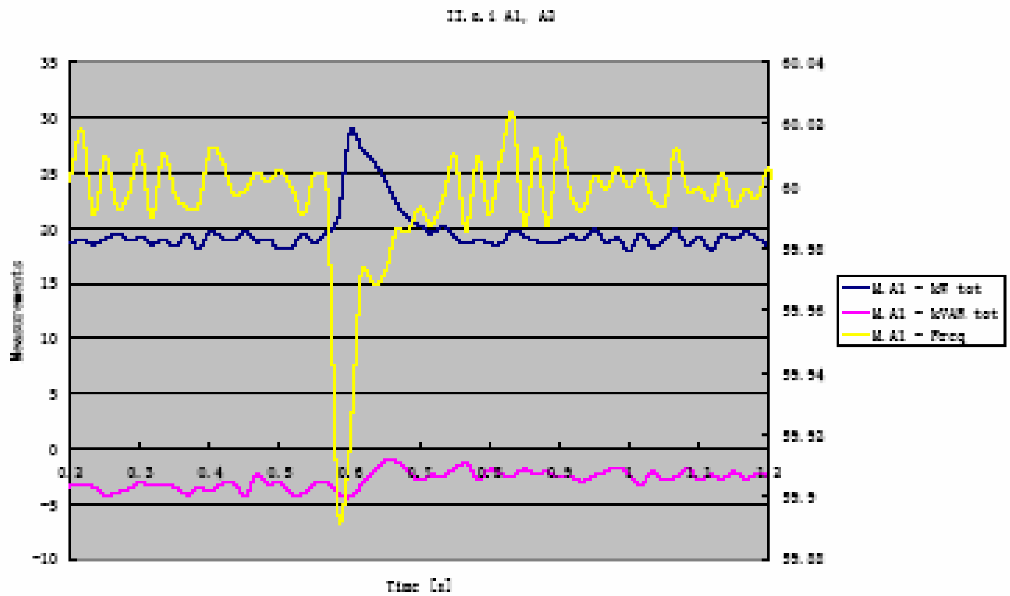


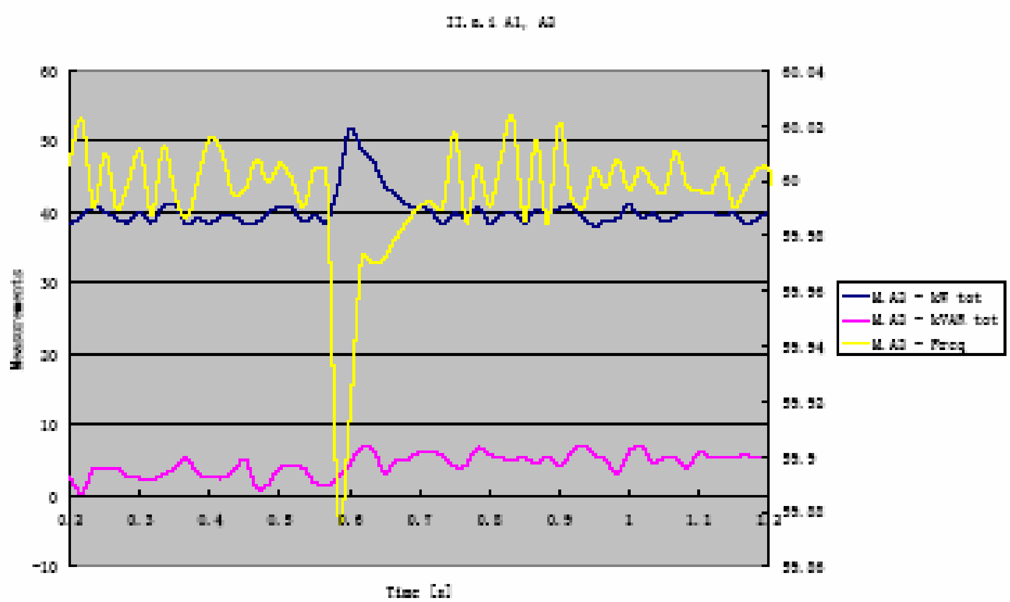


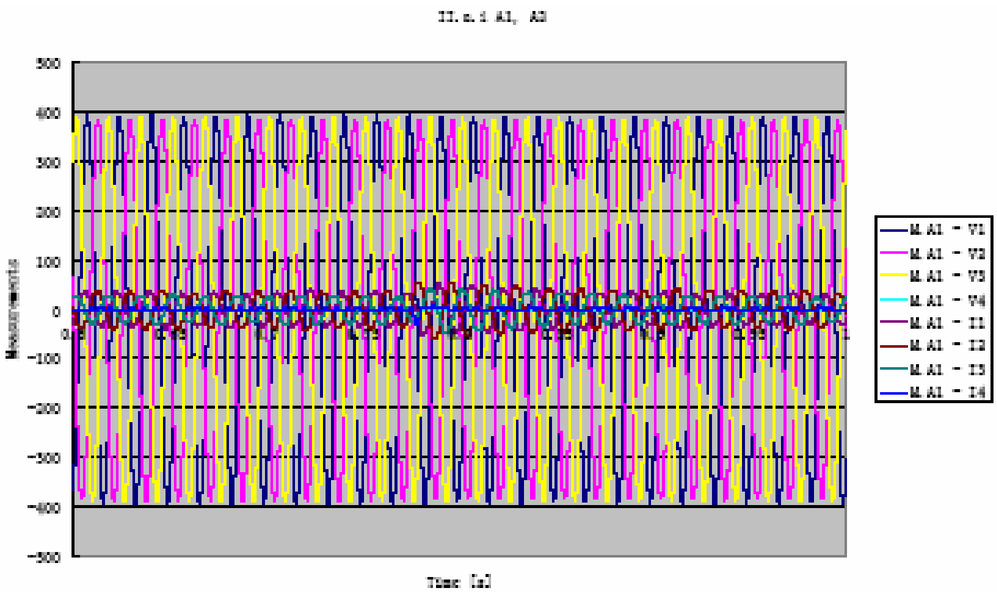


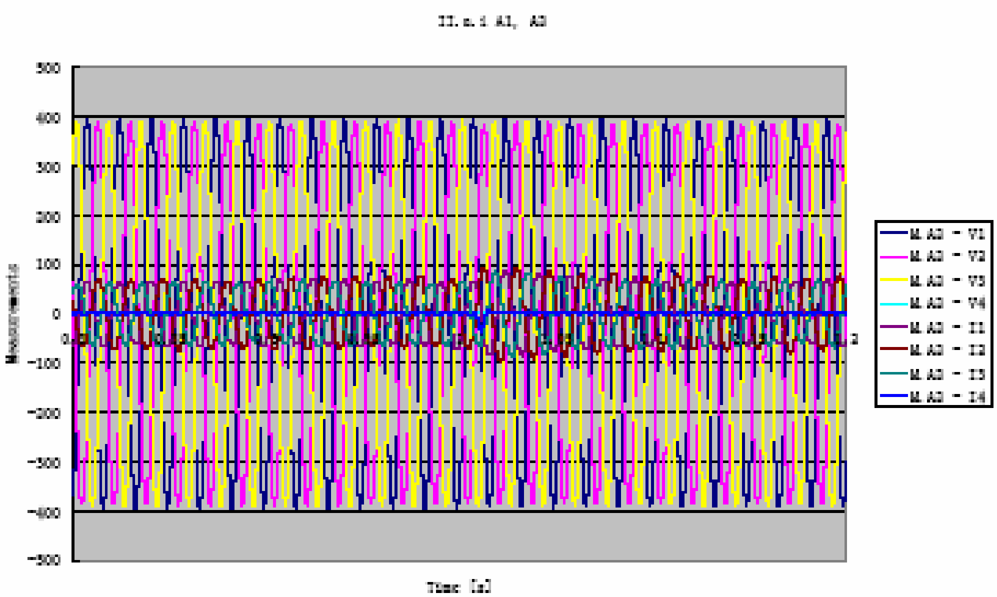
Event not captured

II.a.i with A1 and A2

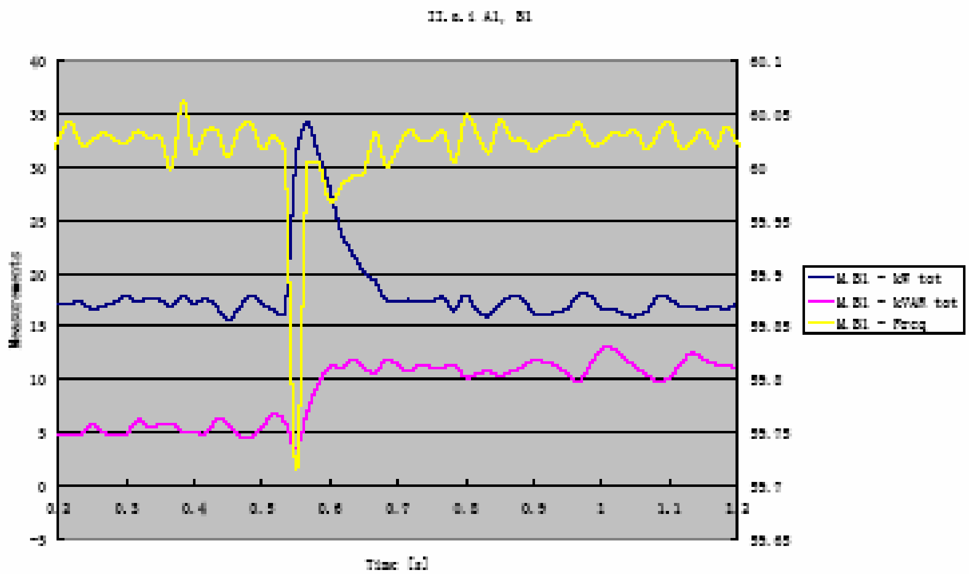


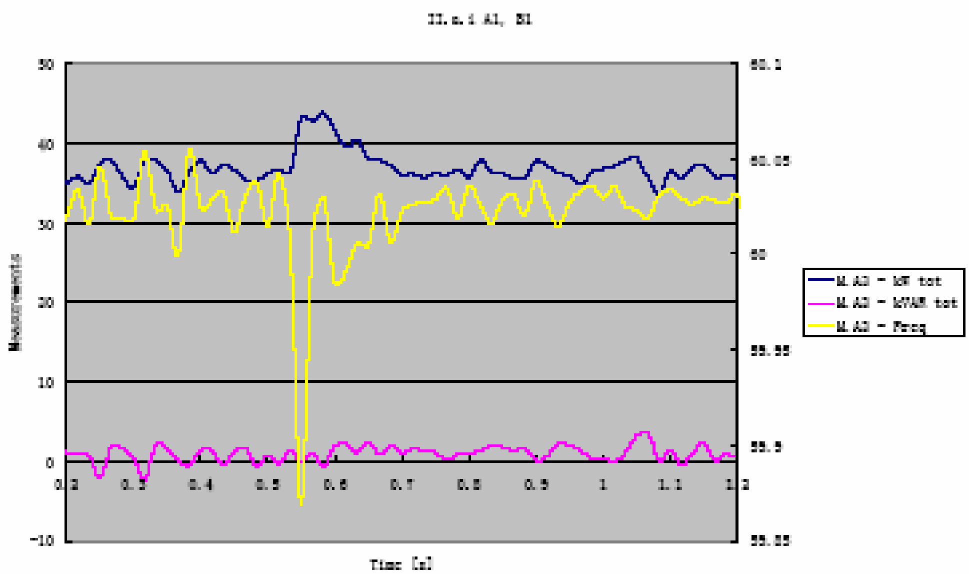



II.a.i A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4

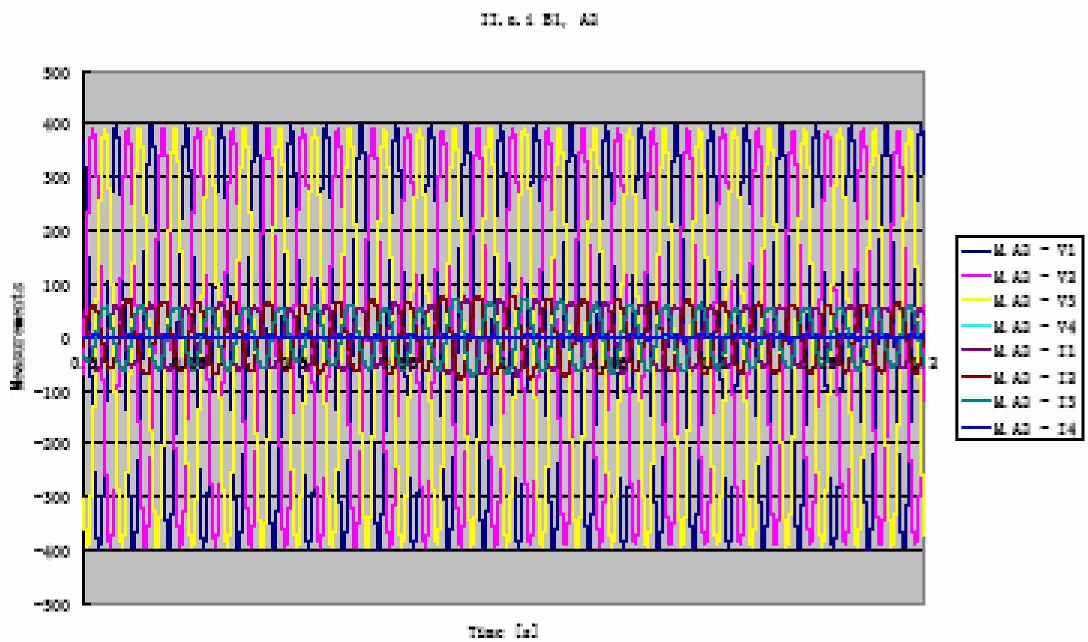

II.a.i A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.a.i with B1 and A2

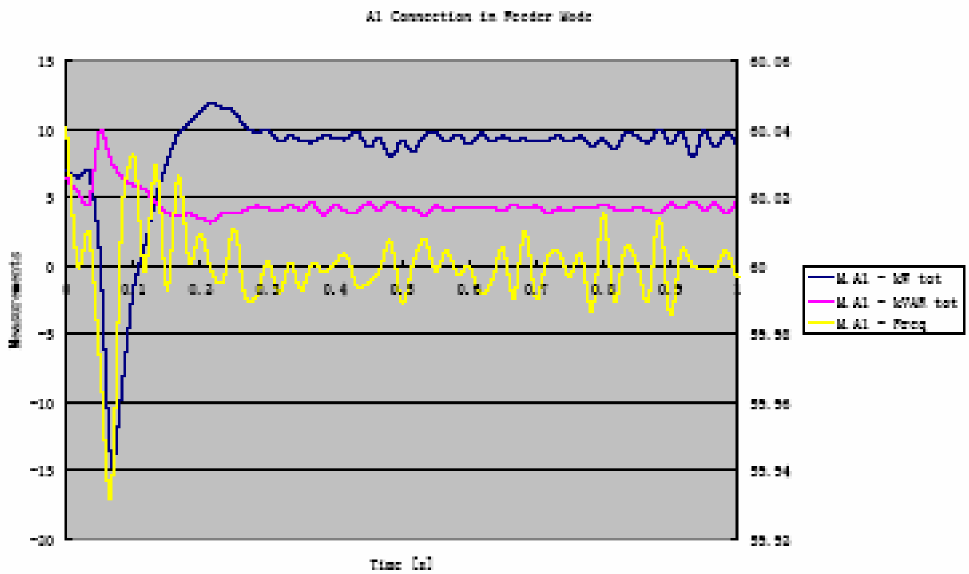


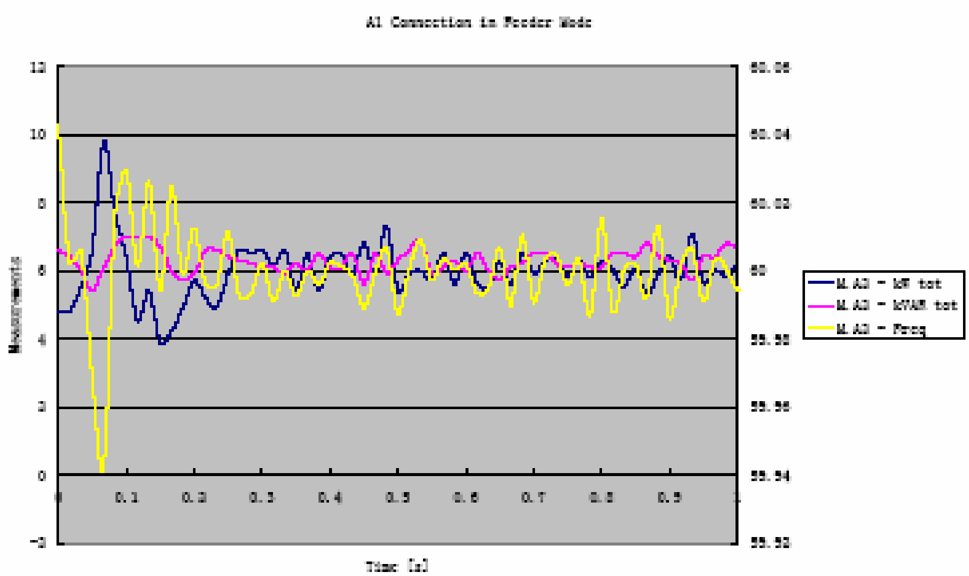


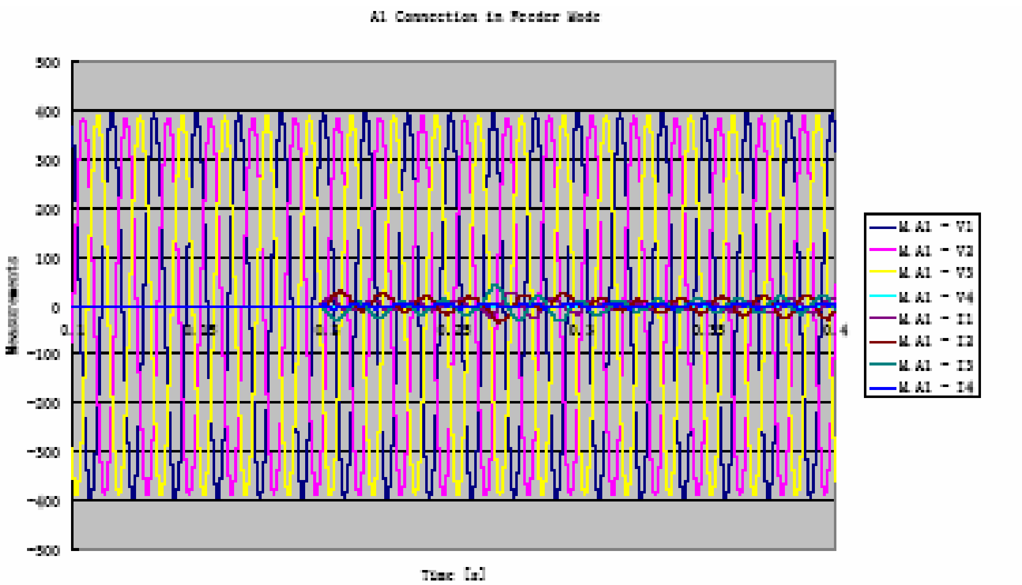
Event not captured

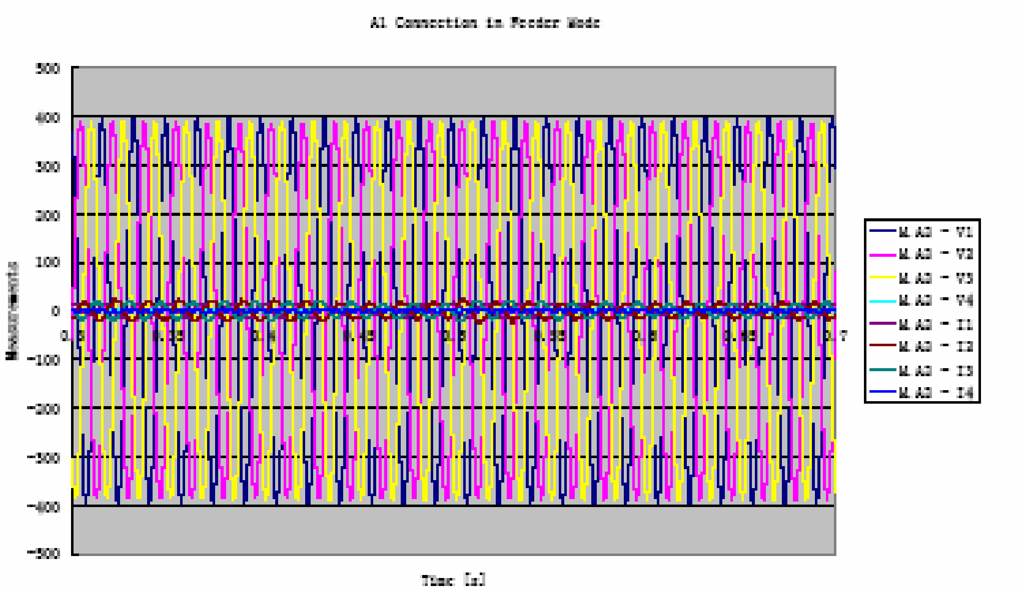


Event to reach III.a.1 with unit A1 and A2 (connection of A1 in feeder mode)

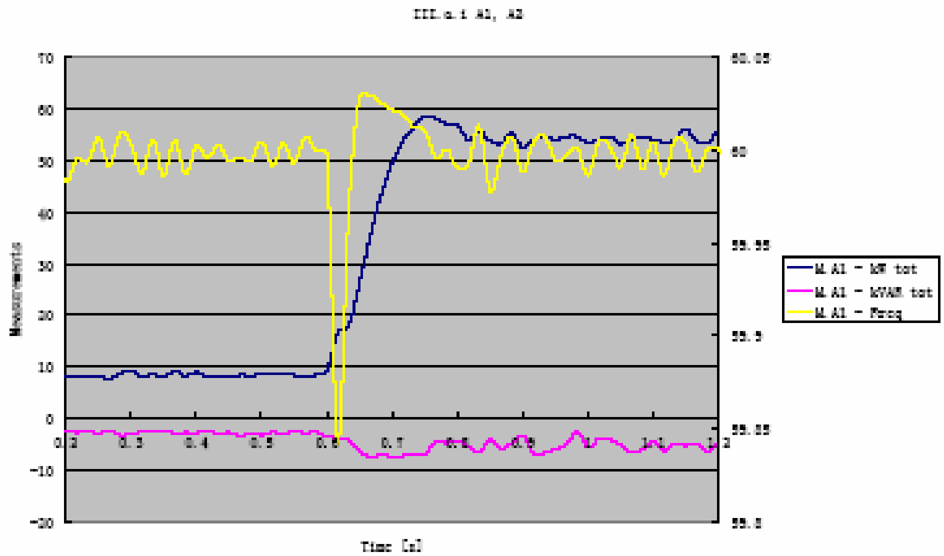


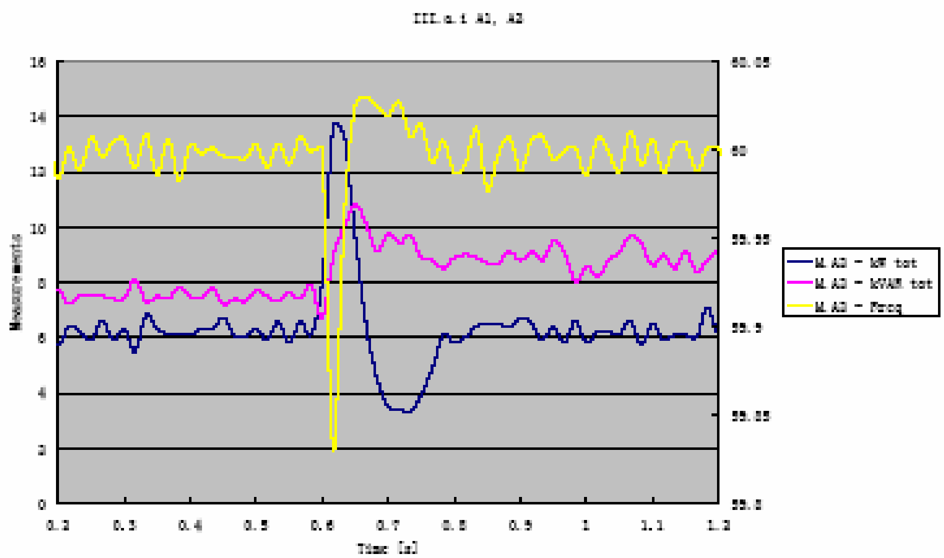


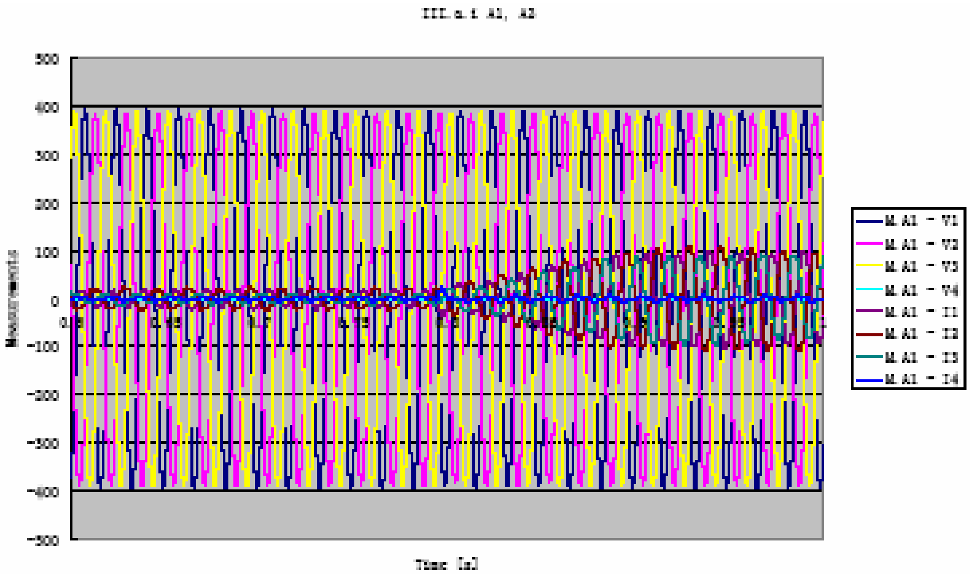

A1 Connection in Feeder Mode
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Time [s]
M A1 - V1
M A1 - V2
M A1 - V3
M A1 - V4
M A1 - I1
M A1 - I2
M A1 - I3
M A1 - I4

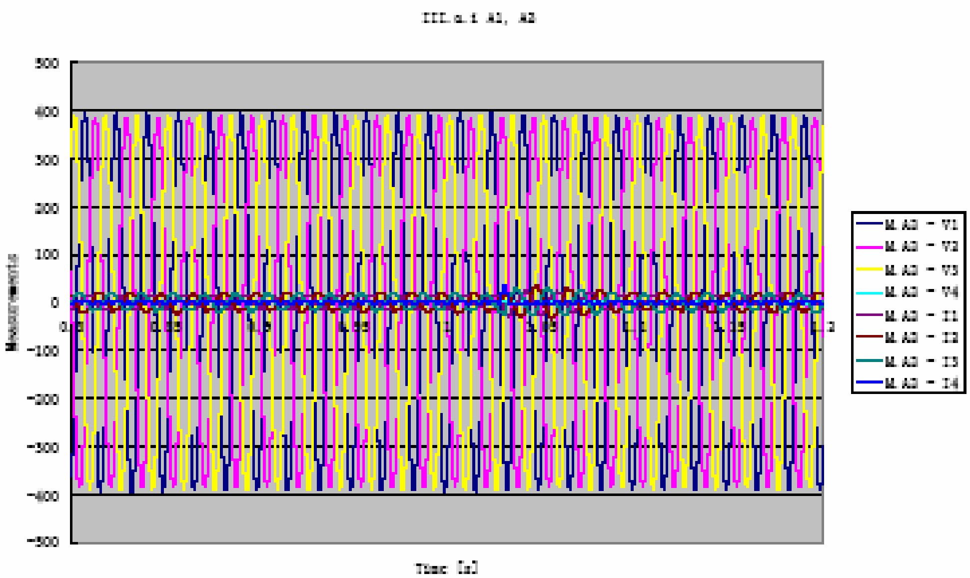

A1 Connection in Feeder Mode
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Time [s]
M A2 - V1
M A2 - V2
M A2 - V3
M A2 - V4
M A2 - I1
M A2 - I2
M A2 - I3
M A2 - I4

III.a.i with unit A1 and A2

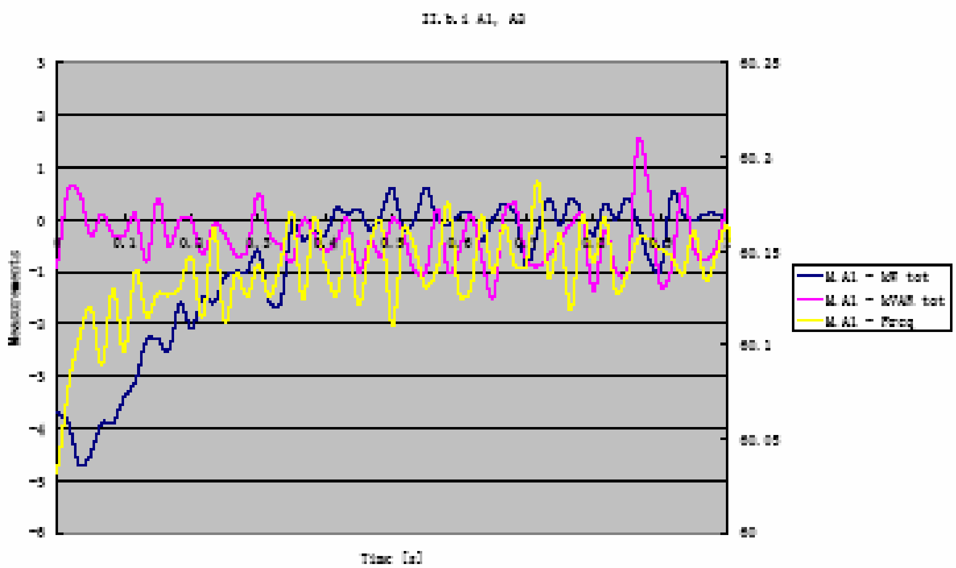


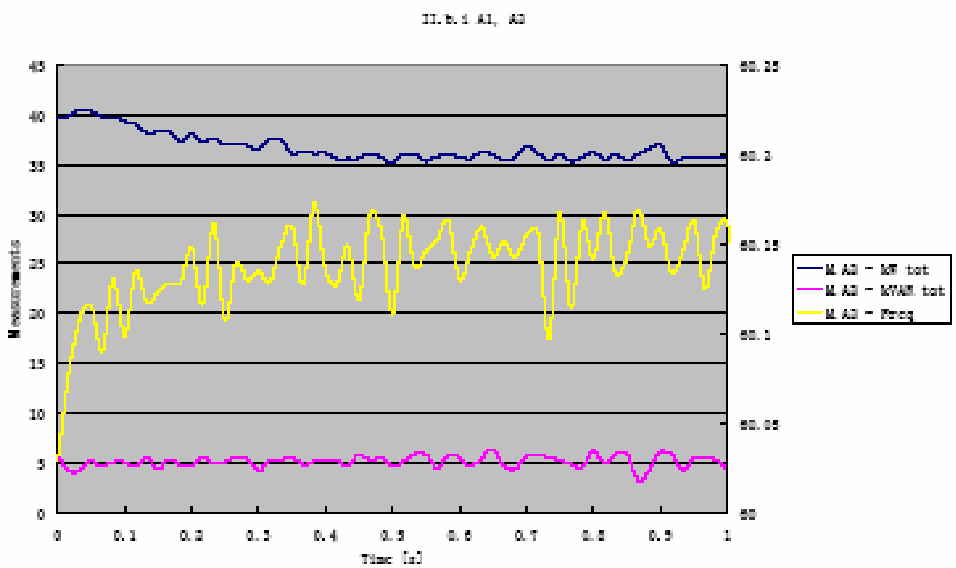


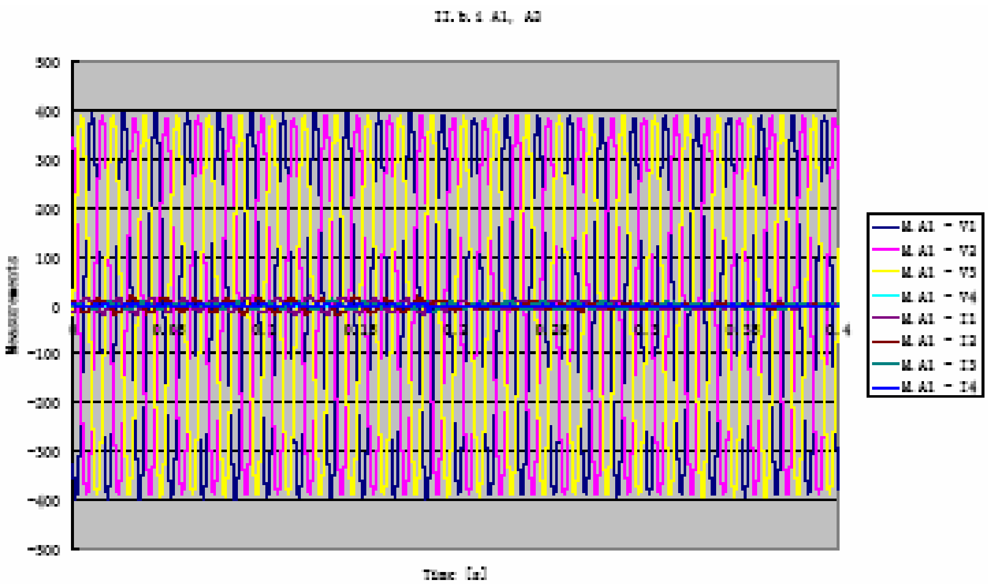

III.a.i A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M. A1 - V1
M. A1 - V2
M. A1 - V3
M. A1 - V4
M. A1 - I1
M. A1 - I2
M. A1 - I3
M. A1 - I4

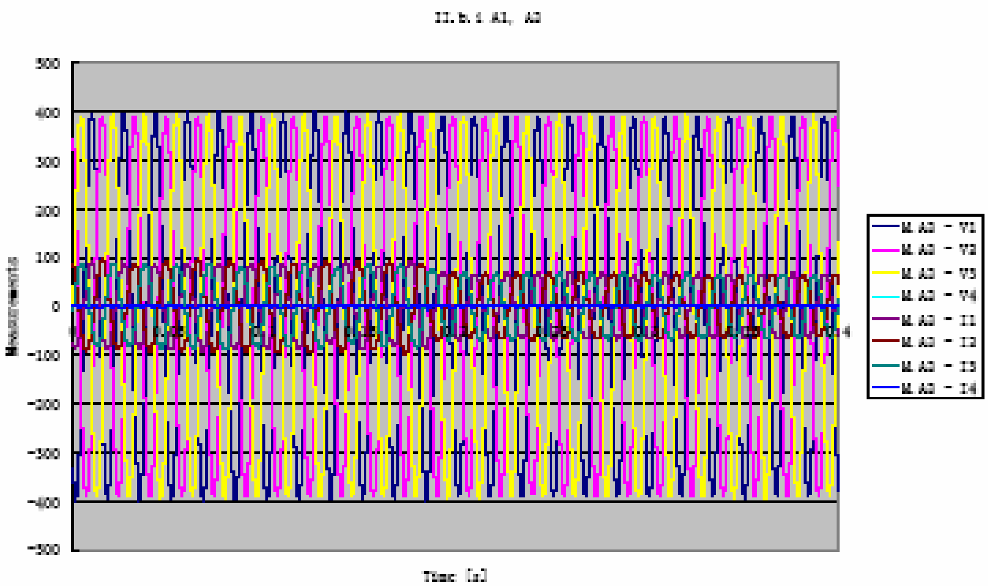

III.a.i A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M. A2 - V1
M. A2 - V2
M. A2 - V3
M. A2 - V4
M. A2 - I1
M. A2 - I2
M. A2 - I3
M. A2 - I4

II.b.i with unit A1 and A2

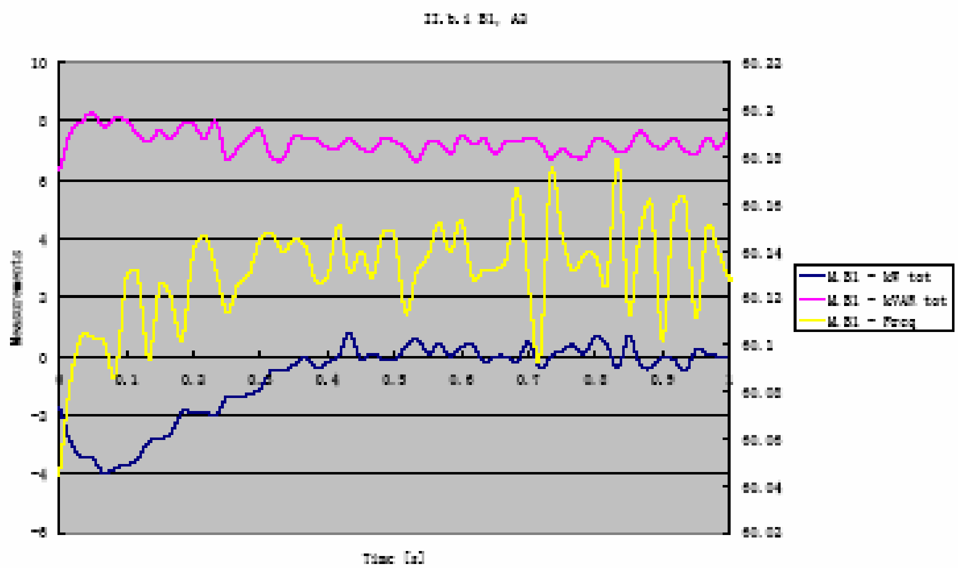


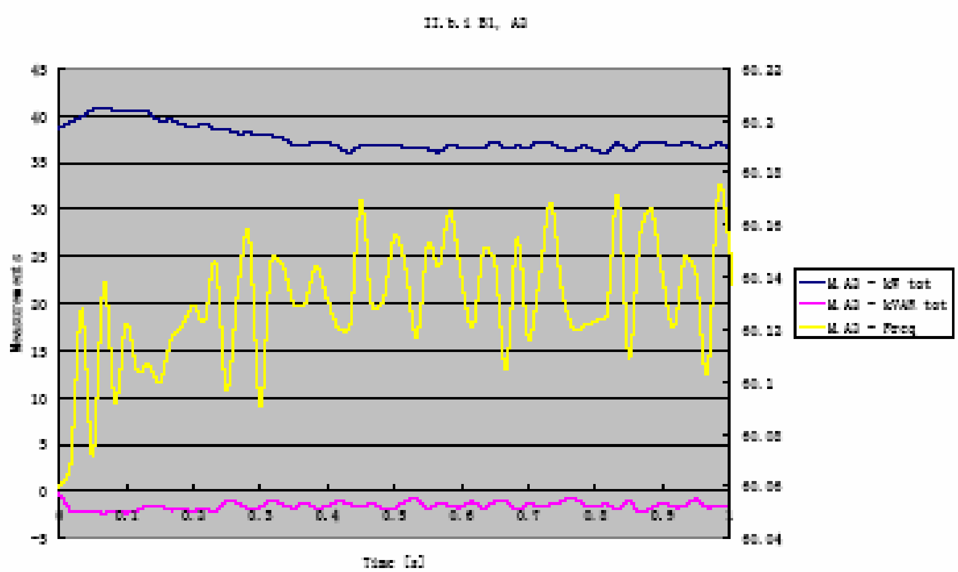


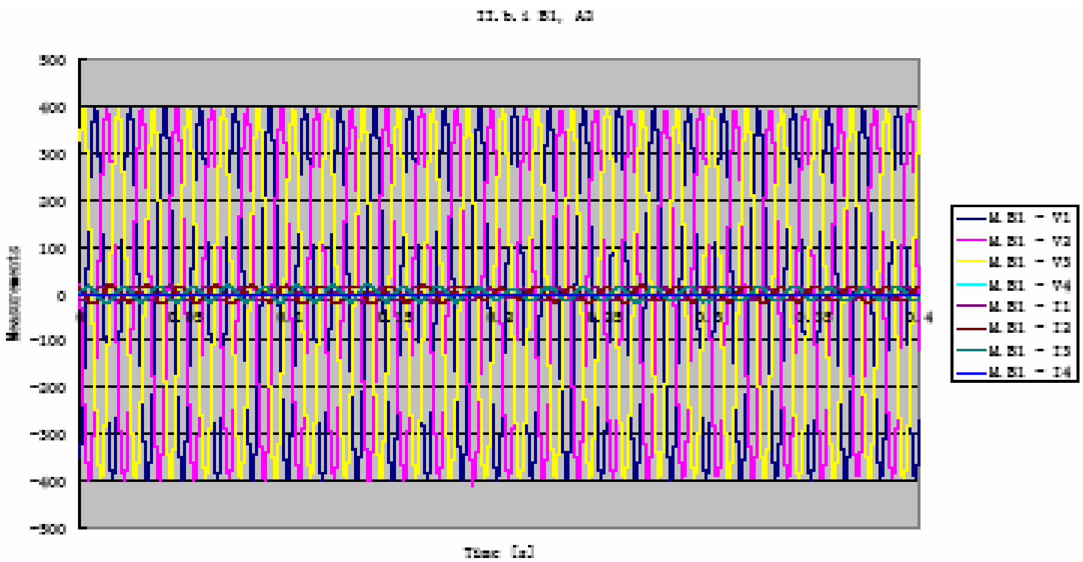

II.b.i A1, A2
Measurements
500
400
300
200
100
0
-100
-200
-300
-400
-500
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4

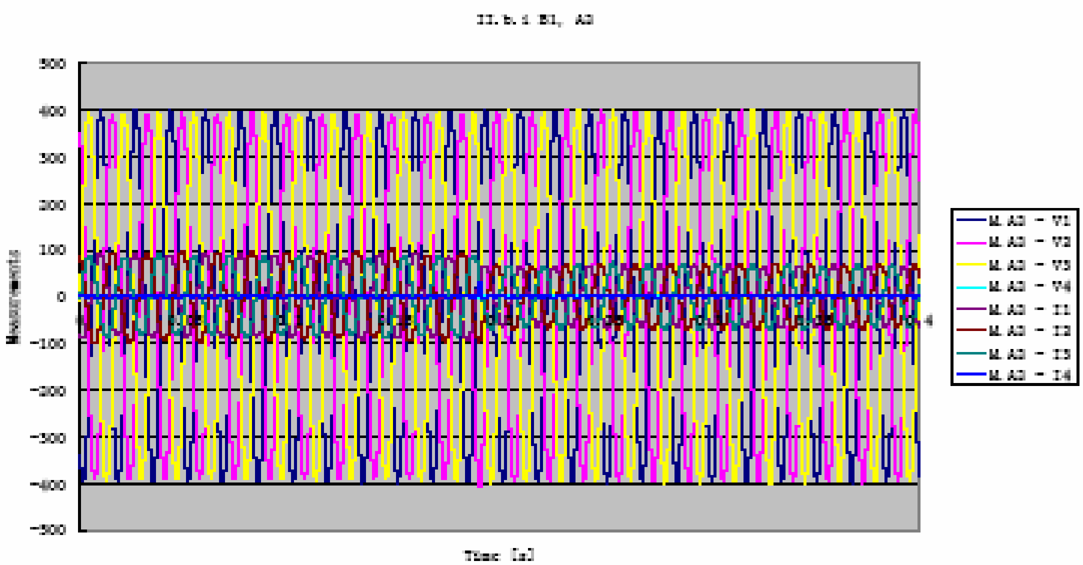

II.b.i A1, A2
Measurements
500
400
300
200
100
0
-100
-200
-300
-400
-500
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.b.i with unit B1 and A2

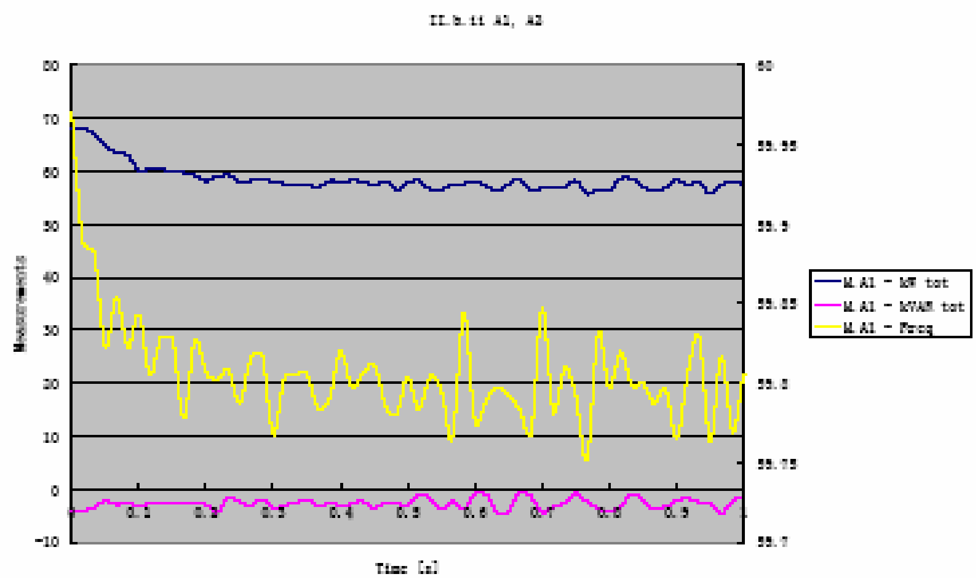


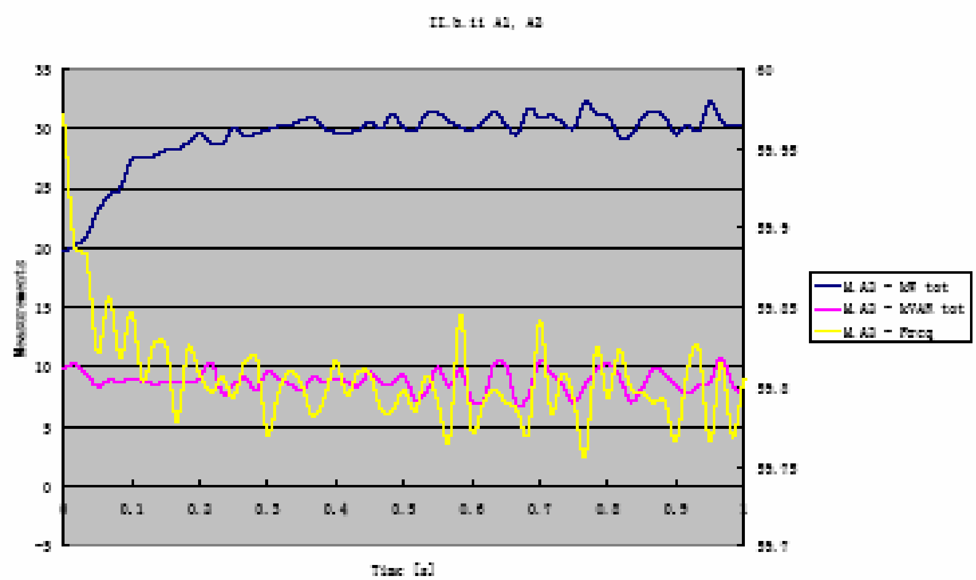


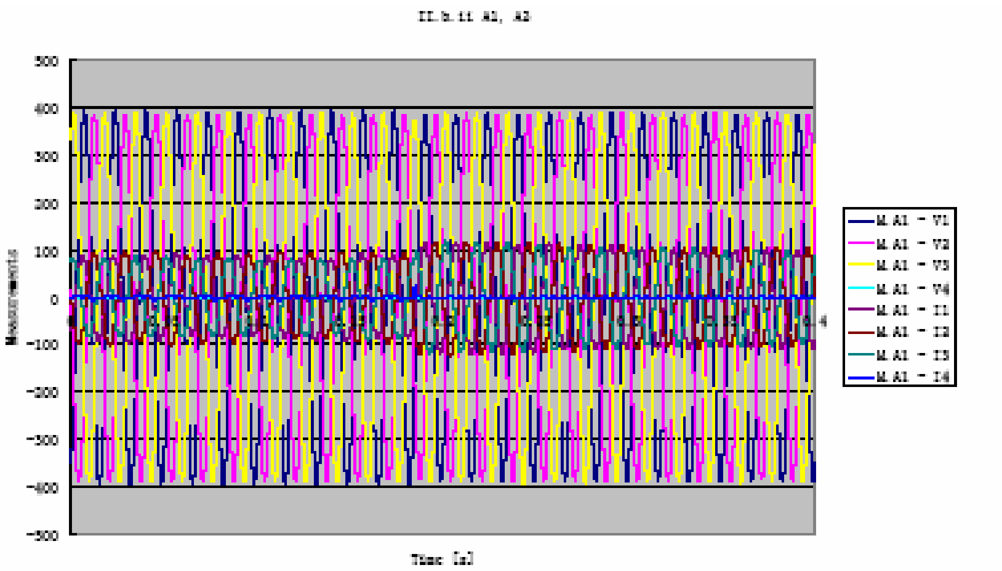

II.b.i B1, A2
Measurements
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Time [s]
M.B1 - V1
M.B1 - V2
M.B1 - V3
M.B1 - V4
M.B1 - I1
M.B1 - I2
M.B1 - I3
M.B1 - I4

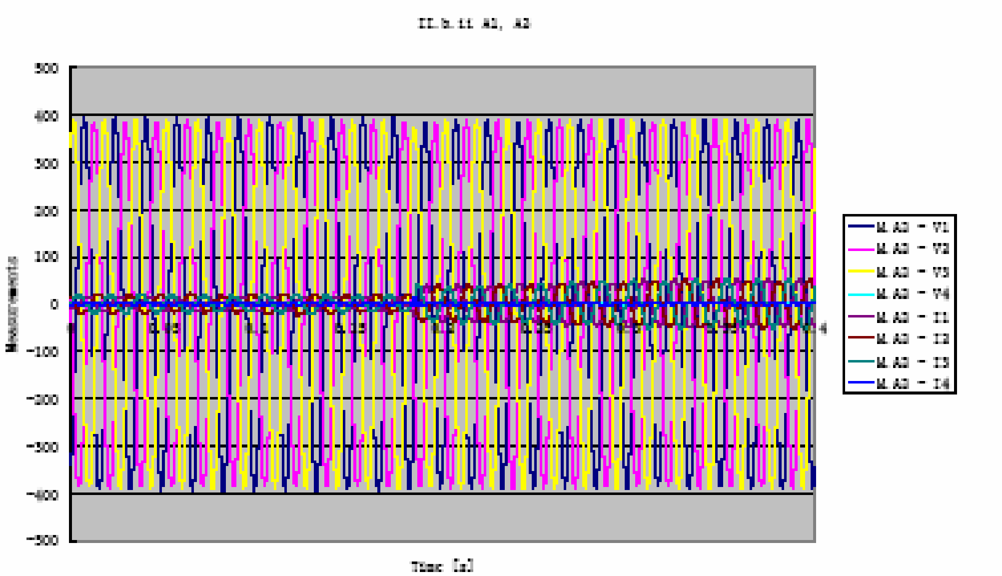

II.b.i B1, A2
Measurements
500
400
300
200
100
0
-100
-200
-300
-400
-500
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.b.ii with units A1 and A2

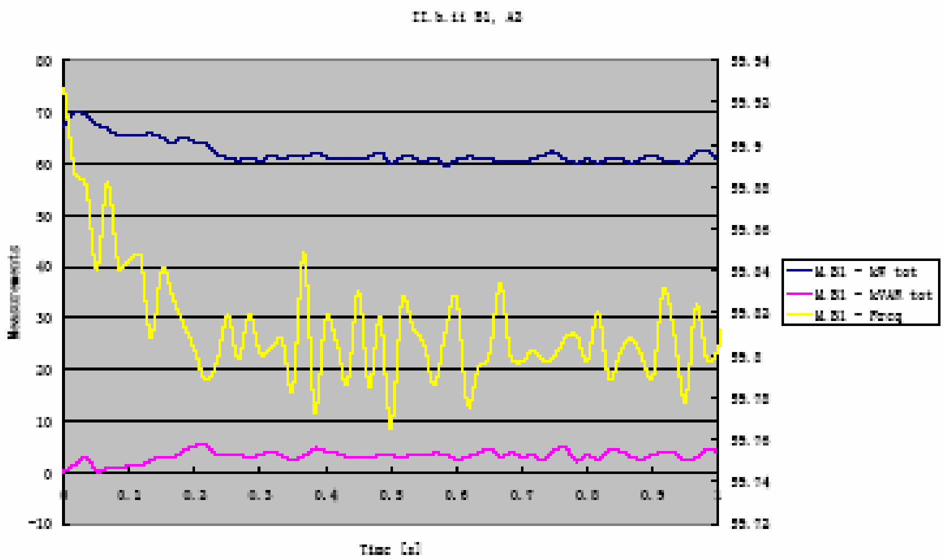


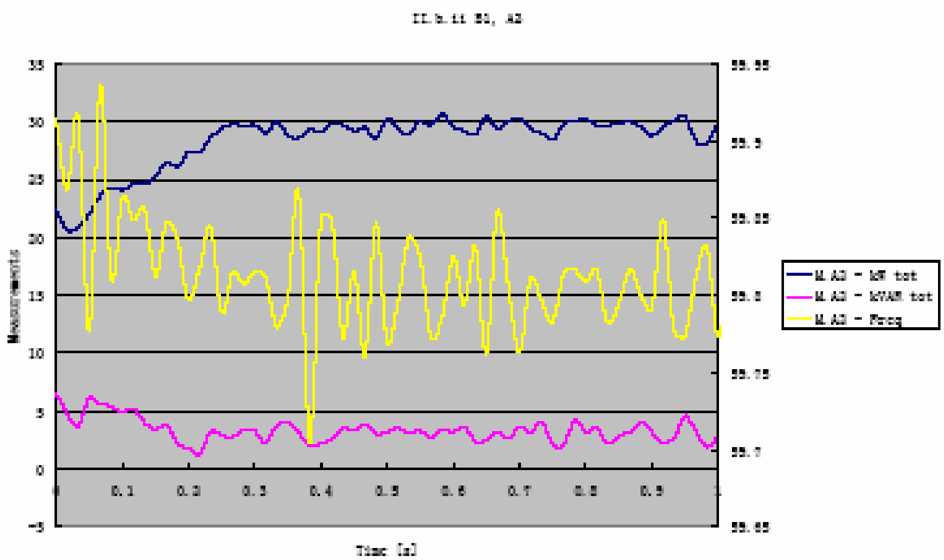


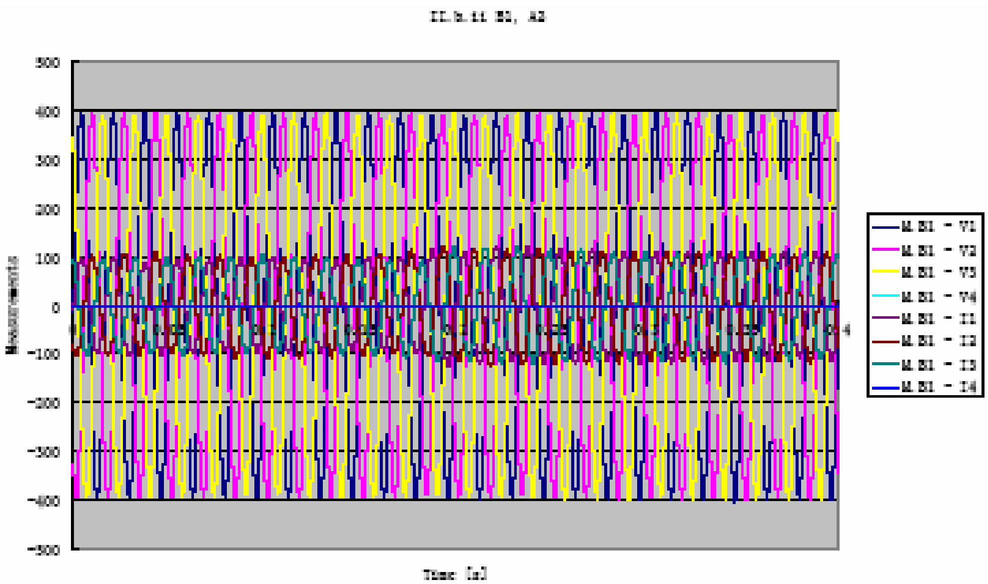

II.b.ii A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4

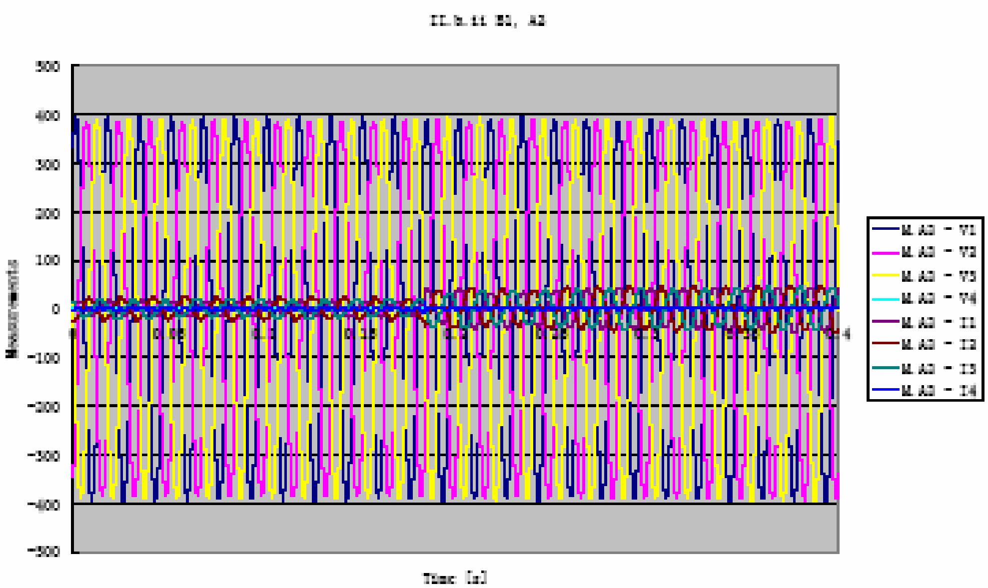

II.b.ii A1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

II.b.ii with units B1 and A2

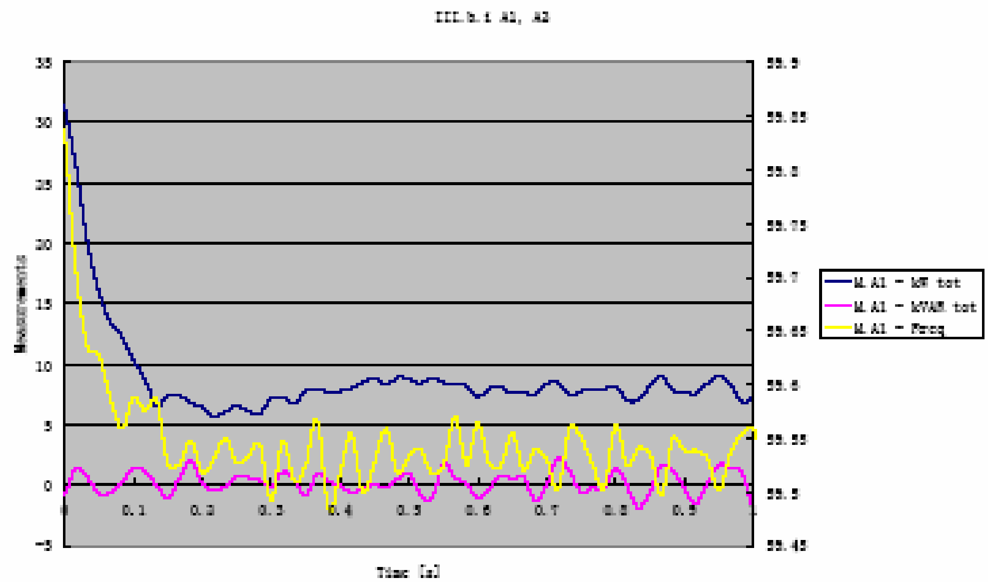


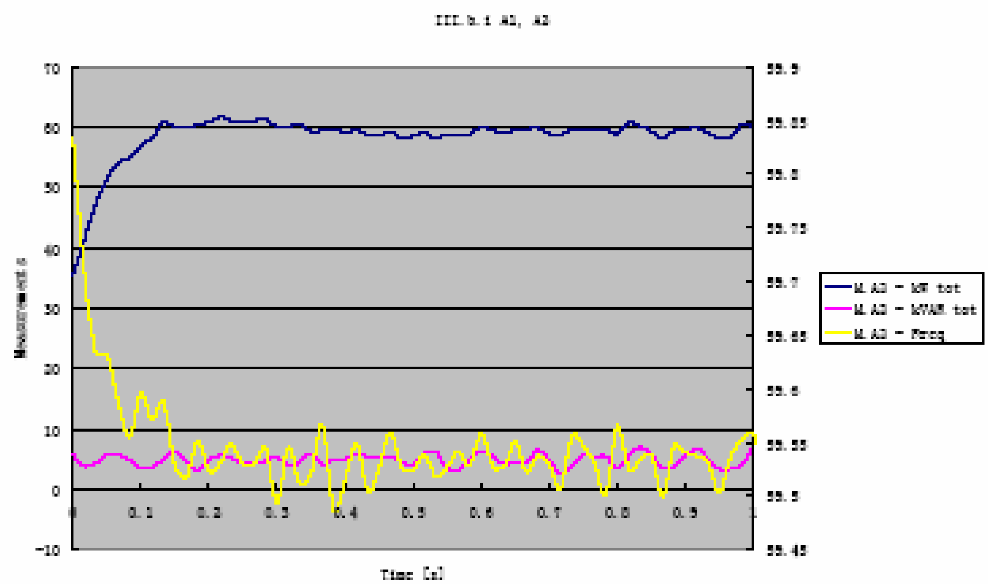


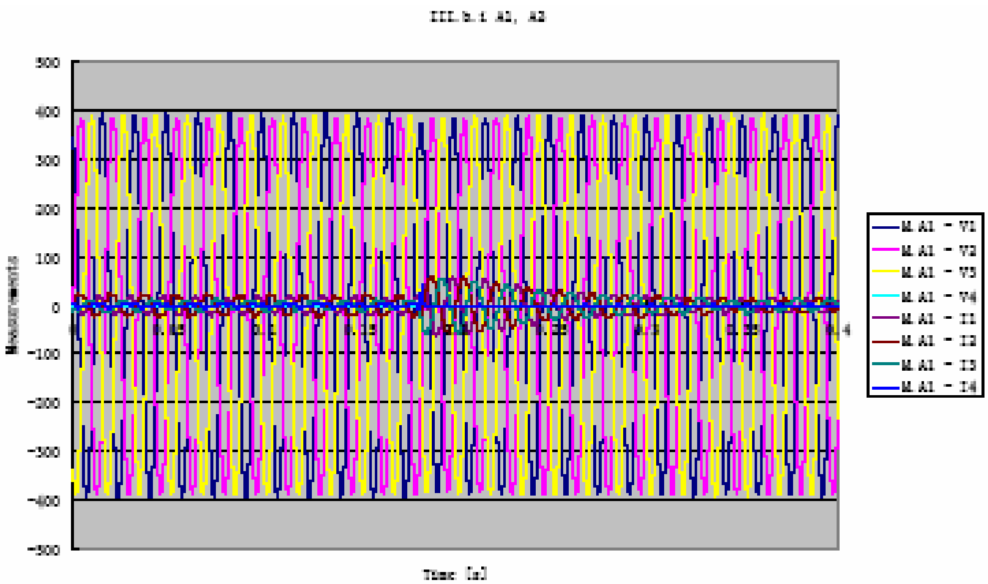

II.b.ii B1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.B1 - V1
M.B1 - V2
M.B1 - V3
M.B1 - V4
M.B1 - I1
M.B1 - I2
M.B1 - I3
M.B1 - I4

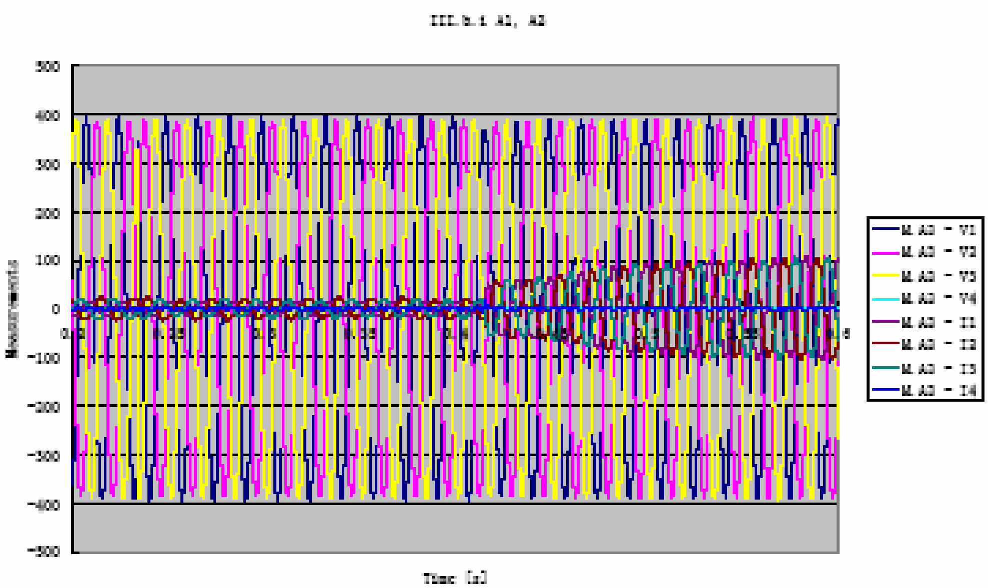

II.b.ii B1, A2
500
400
300
200
100
0
-100
-200
-300
-400
-500
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

III.b.i with unit A1 and A2






III.b.1 A1, A2
Measurements
Time [s]
M.A1 - V1
M.A1 - V2
M.A1 - V3
M.A1 - V4
M.A1 - I1
M.A1 - I2
M.A1 - I3
M.A1 - I4


III.b.1 A1, A2
Measurements
Time [s]
M.A2 - V1
M.A2 - V2
M.A2 - V3
M.A2 - V4
M.A2 - I1
M.A2 - I2
M.A2 - I3
M.A2 - I4

14. Oscilloscope Waveforms, Unit A2, 10-11-06

Oscilloscope waveforms with and without weakened genset

This report focuses in identifying the contributions of the surge module to the operation of a single genset during several loading and unloading conditions. It was shown that the new stiff engine control would survive all the load changes without the assistance of the surge module. For that, see data in "10_11_06_test_results.pdf", obtained with surge module off and engine running at 2000rpm.

This document shows the oscilloscope traces obtained with the stiff control at unit A1 in two basic series of tests: A) with the engine setpoint 2000rpm and the surge module on at all times; B) with a weakened engine, operating at a 1850rpm setpoint and with the surge module on in some tests and off in others.

The traces show a matrix of plots with DC bus voltage, surge module current, inverter current and voltage, synchronous machine current and engine rpm. The speed was calculated from zero crossing of the synch. mach. current.

The other time (i.e. "Oscilloscope_8_31_06.pdf") the DC bus voltage was obtained from subtracting low rail voltage from the high rail voltage. At this time, only the high rail voltage was captured: the full rail to rail voltage was calculated multiplying by two this available voltage.

The two series of tests can be found:

Notes:

i) the current from the surge module (when it is activated) seems to be larger than previously measured in August. I am not sure if before there was a filter in the probe and this time it was without the filtering. Or the issue could be related to the sampling rate. The average current should be equal to 20A.

ii) in the case A) with load from 60kW => 0, (Figure 6) the DC bus exceeds 900V. It could be that the mid point voltage experienced a sag and the high rail was larger than the low rail. Because this plot was obtained by multiplying by two the high rail voltage, it is possible that the actual overall DC bus never exceeded 900V.

iii) I agree with Dave that when the surge module is injecting current, the sychronous machine current has a strong non zero DC offset. This behaviour was identically present also in the August waveforms.

A) Engine at 2000 RPM

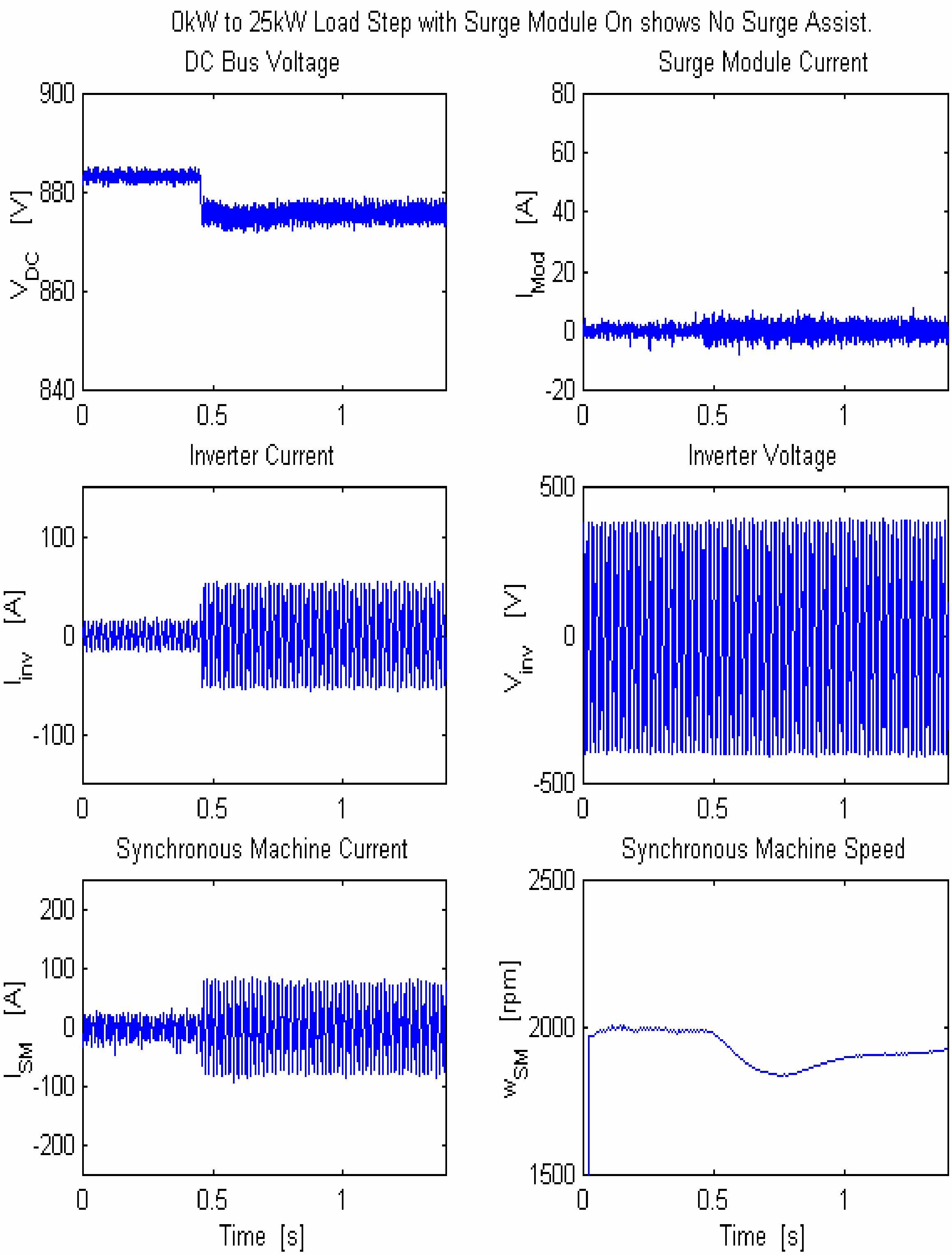
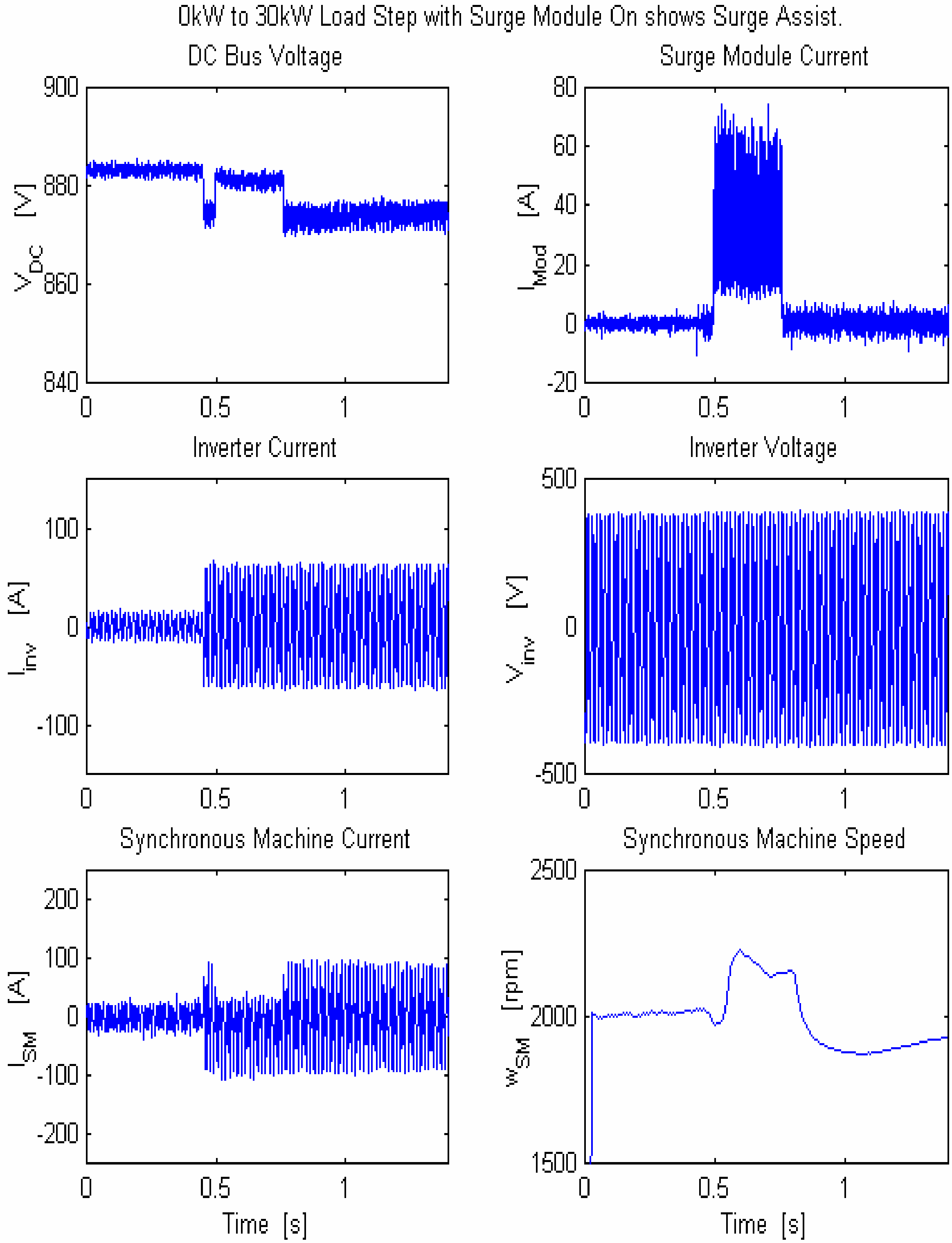
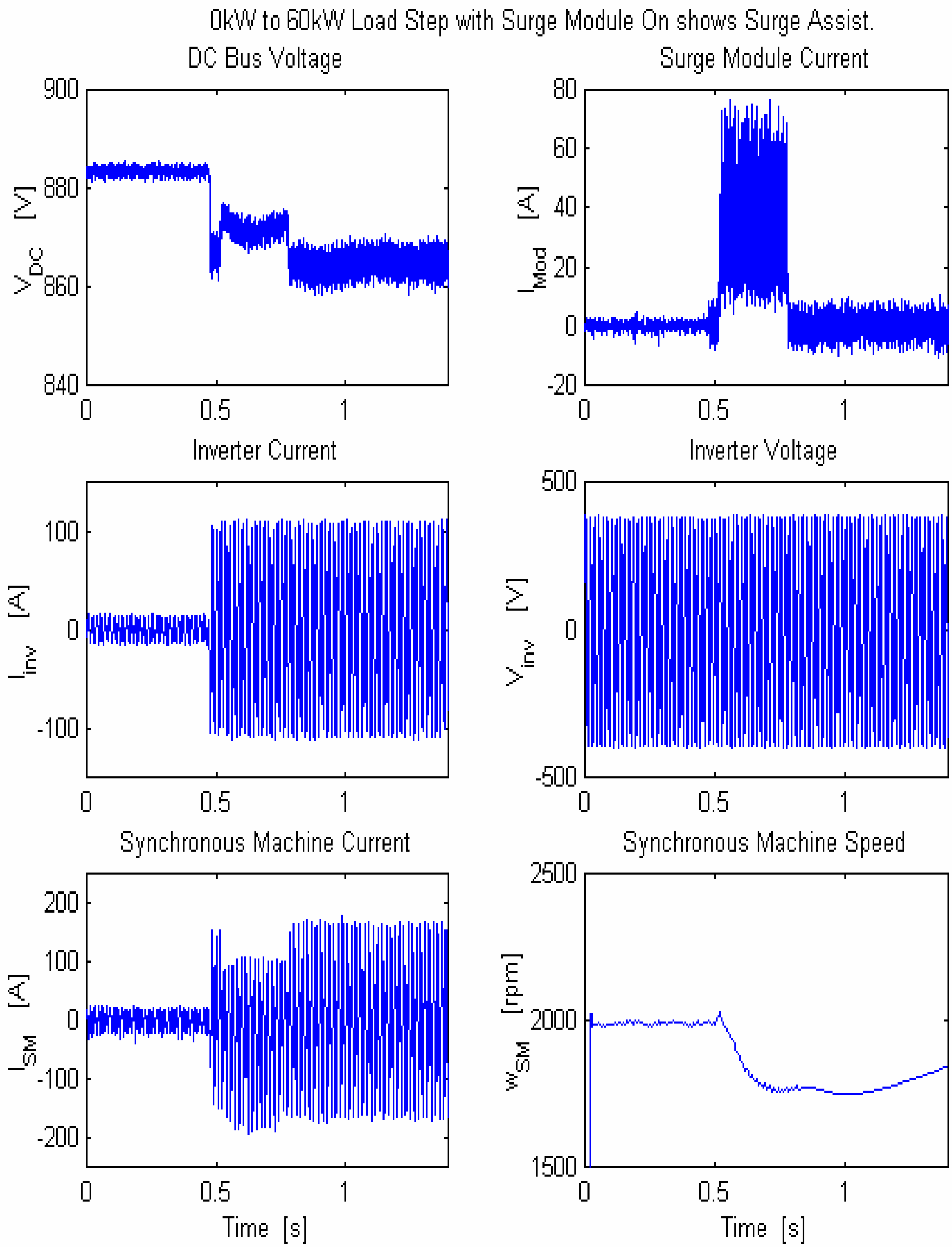


Figure 1.



0kW to 30kW Load Step with Surge Module On shows Surge Assist.
DC Bus Voltage
V_DC [V]
900
880
860
840
0
0.5
1
Surge Module Current
I_Mod [A]
80
60
40
20
0
-20
0
0.5
1
Inverter Current
I_inv [A]
100
0
-100
0
0.5
1
Inverter Voltage
V_inv [V]
500
0
-500
0
0.5
1
Synchronous Machine Current
I_SM [A]
200
100
0
-100
-200
0
0.5
1
Time [s]
Synchronous Machine Speed
w_SM [rpm]
2500
2000
1500
0
0.5
1
Time [s]

Figure 2.



0kW to 60kW Load Step with Surge Module On shows Surge Assist.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 3.

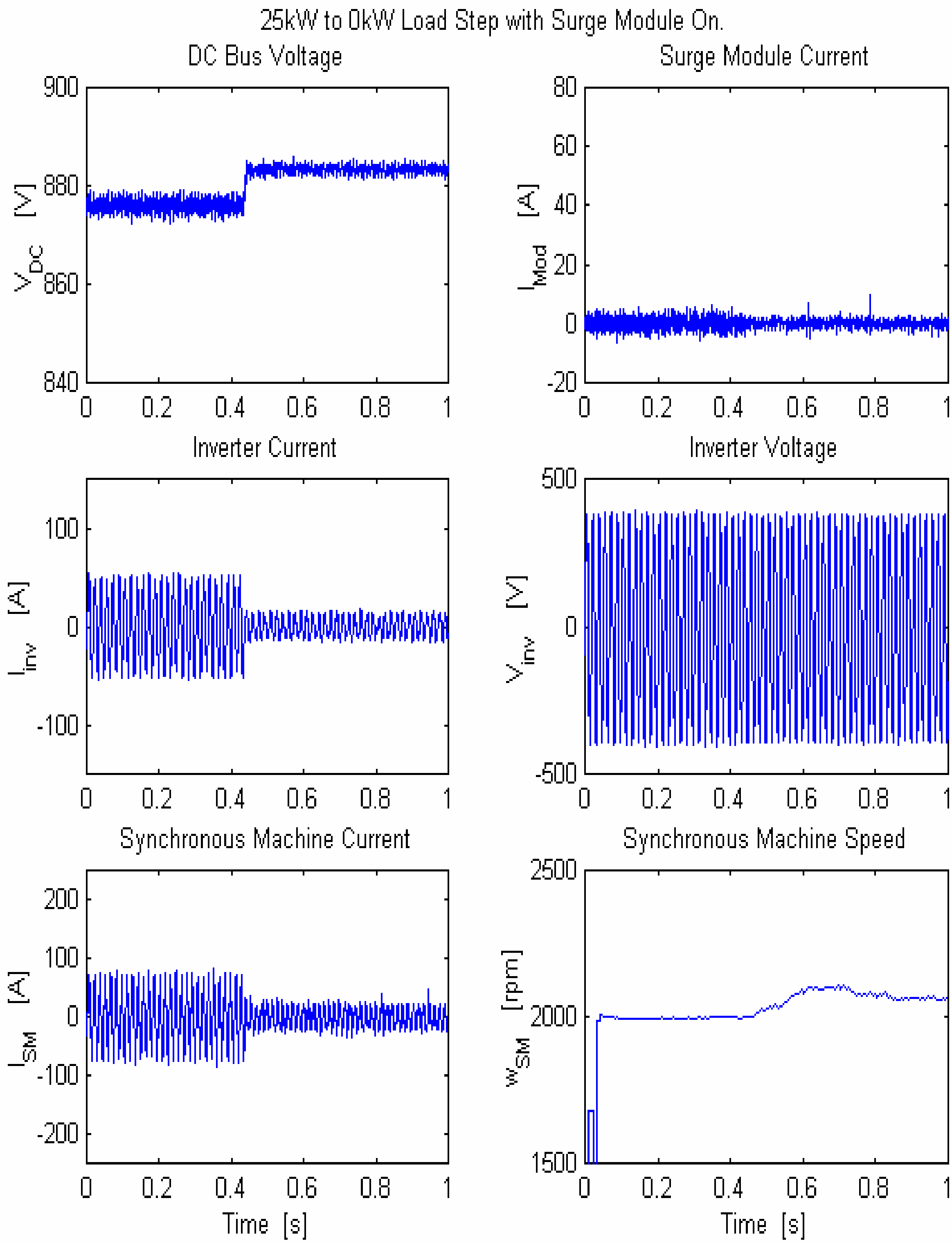
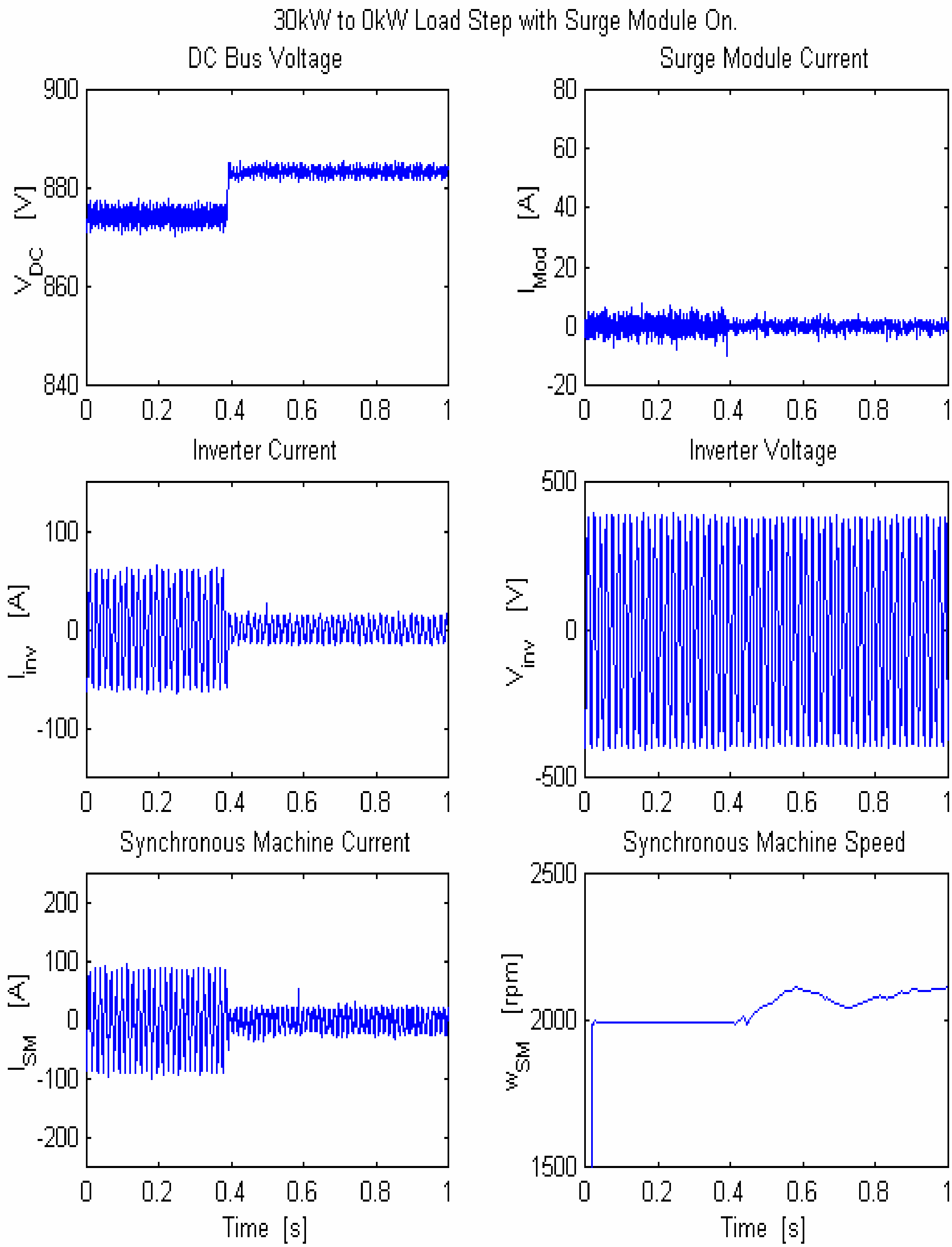

25kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_{DC} [V]
I_{Mod} [A]
I_{inv} [A]
V_{inv} [V]
I_{SM} [A]
w_{SM} [rpm]
Time [s]
Time [s]

Figure 4.



30kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 5.

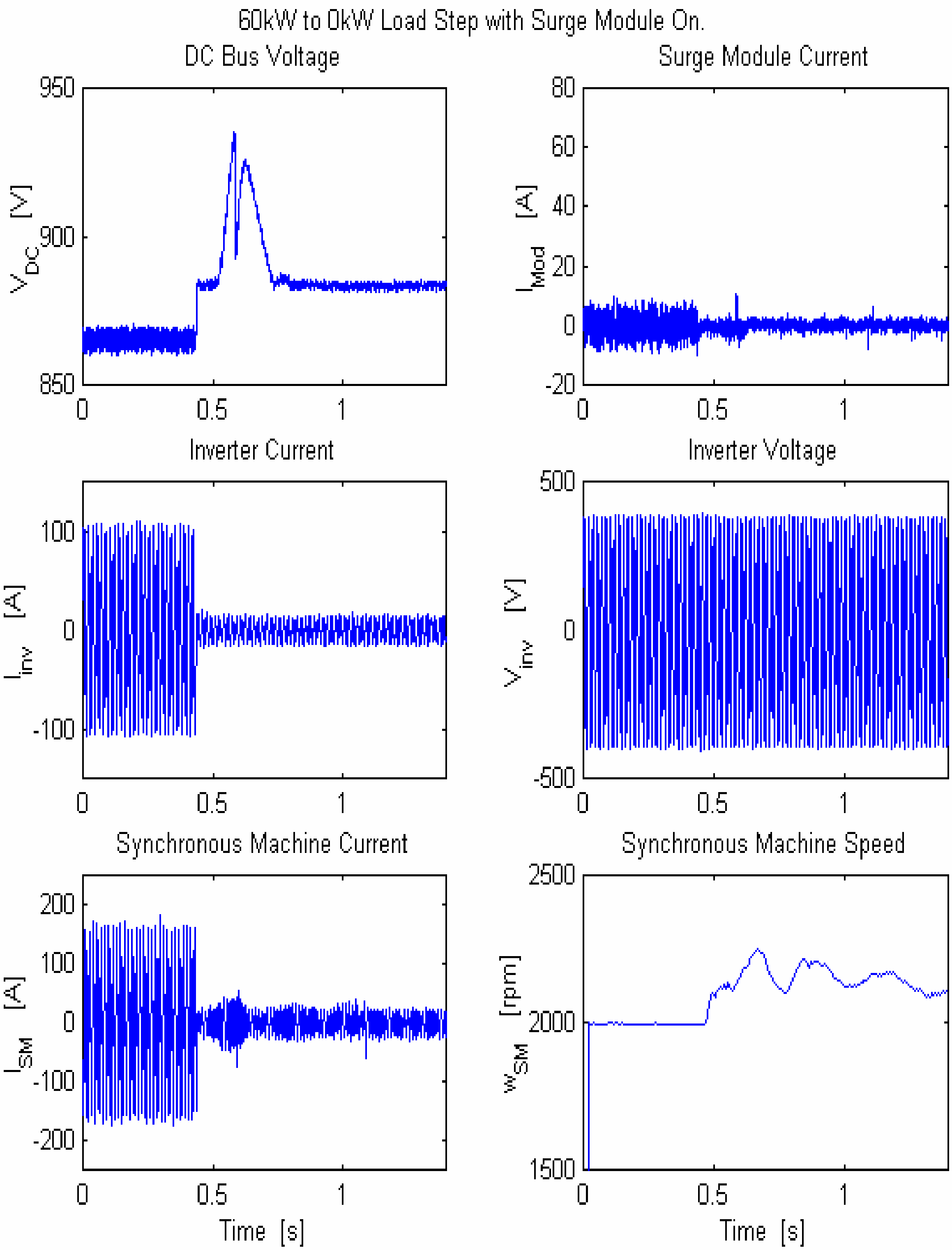

60kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
950
900
850
V_{DC} [V]
0
0.5
1
Surge Module Current
80
60
40
20
0
-20
I_{Mod} [A]
0
0.5
1
Inverter Current
100
0
-100
I_{inv} [A]
0
0.5
1
Inverter Voltage
500
0
-500
V_{inv} [V]
0
0.5
1
Synchronous Machine Current
200
100
0
-100
-200
I_{SM} [A]
0
0.5
1
Time [s]
Synchronous Machine Speed
2500
2000
1500
w_{SM} [rpm]
0
0.5
1
Time [s]

Figure 6.

B) Engine at 1850 RPM

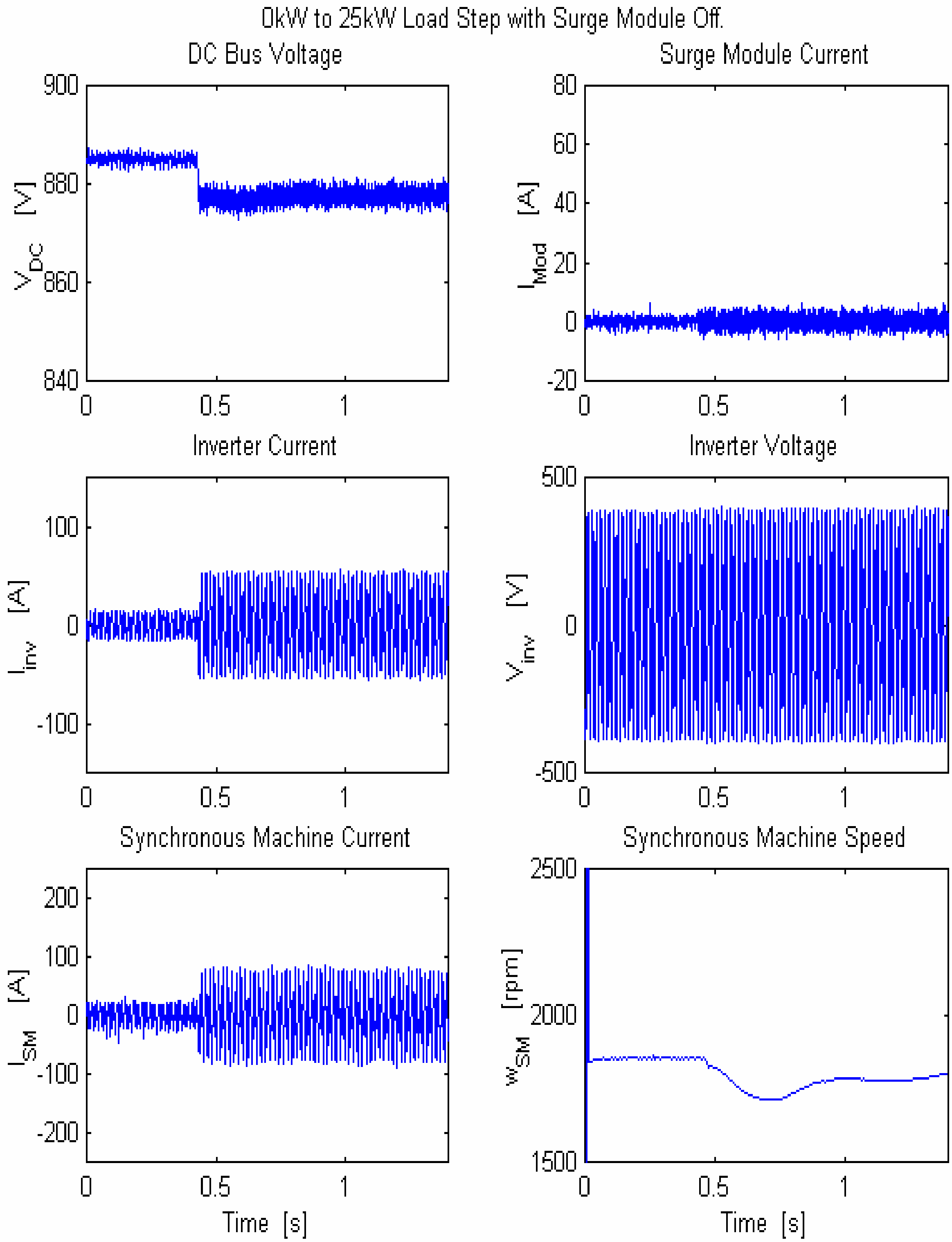


Figure 7.

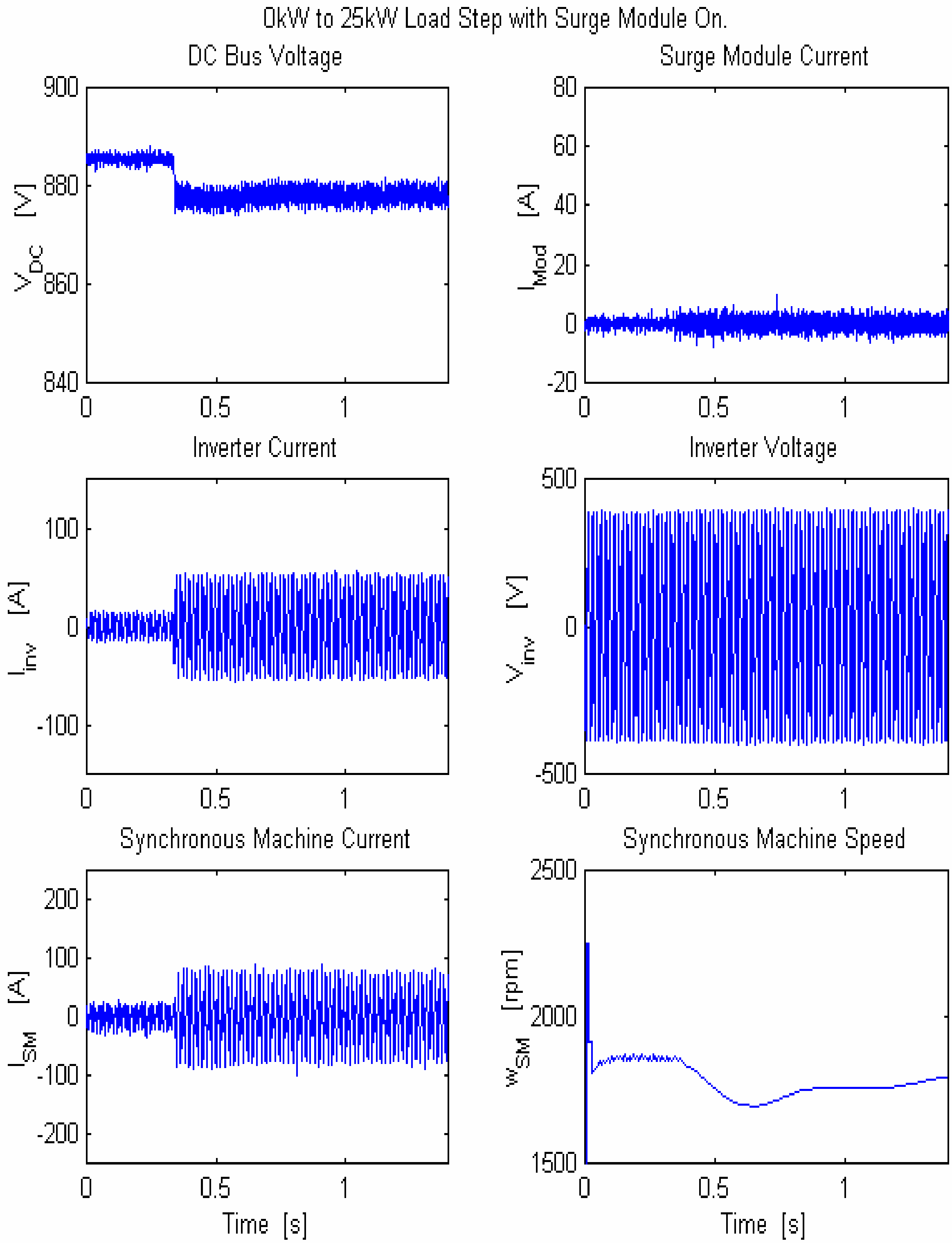

0kW to 25kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 8.

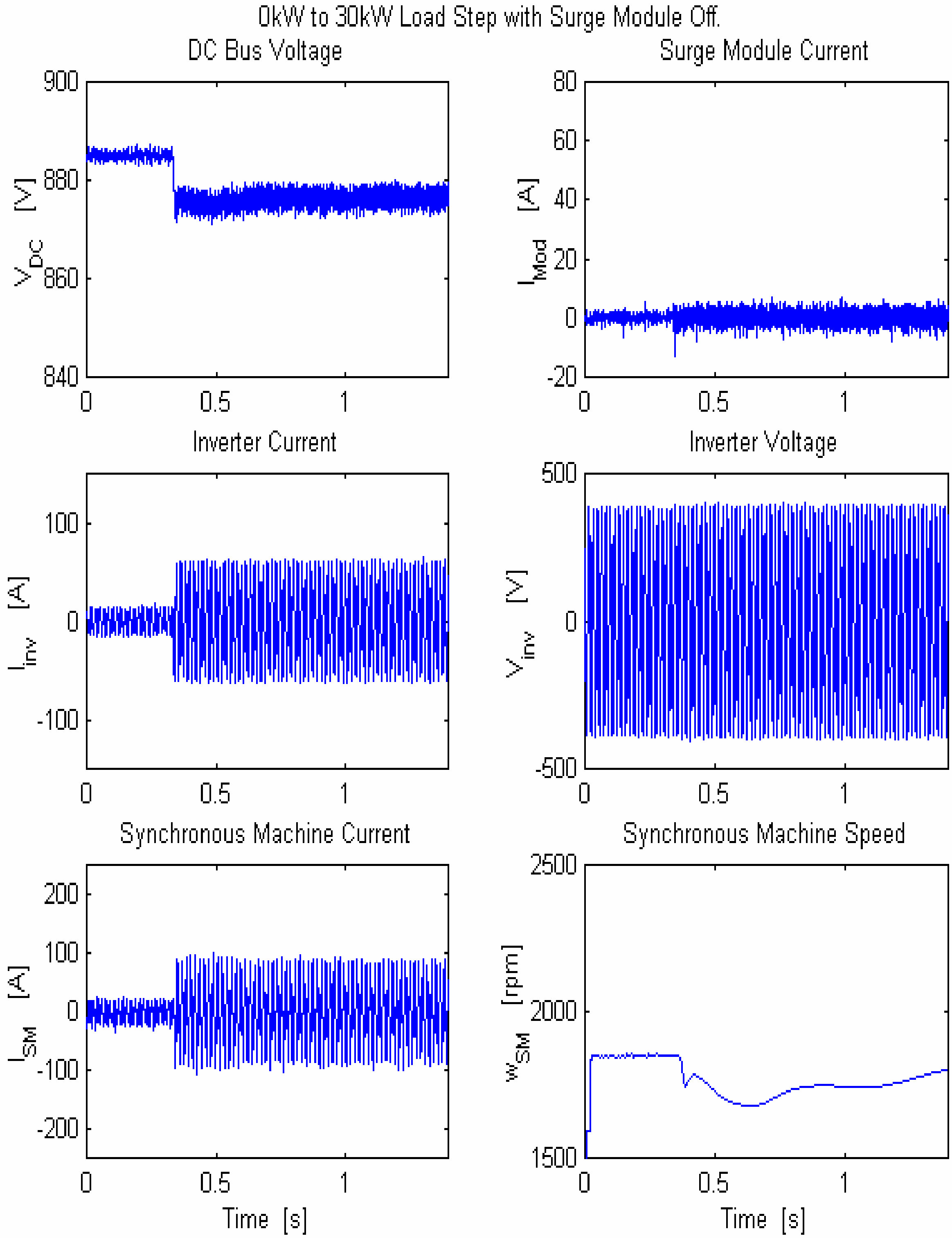

0kW to 30kW Load Step with Surge Module Off.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_{DC} [V]
I_{Mod} [A]
I_{inv} [A]
V_{inv} [V]
I_{SM} [A]
w_{SM} [rpm]
Time [s]
Time [s]

Figure 9.

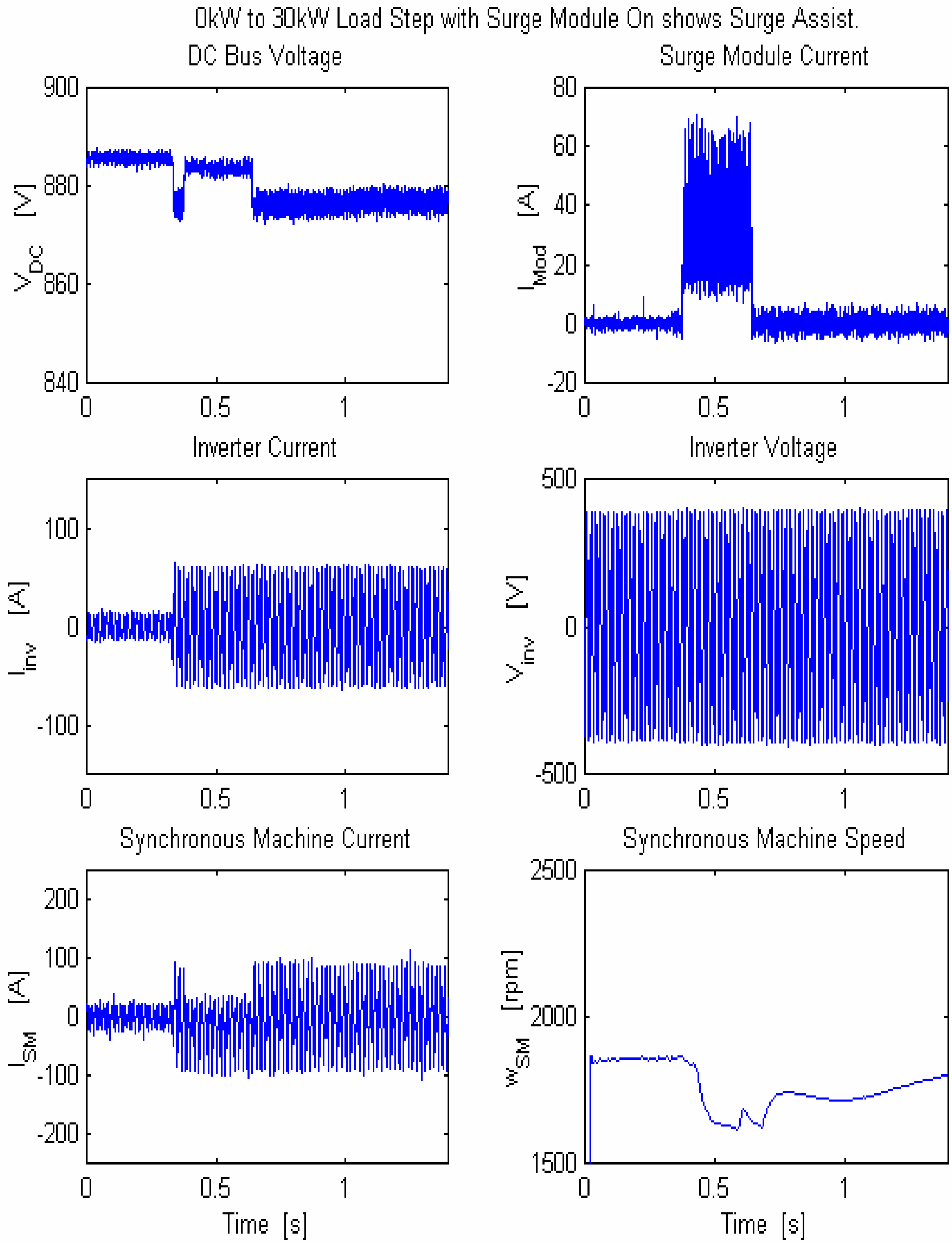

0kW to 30kW Load Step with Surge Module On shows Surge Assist.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 10.

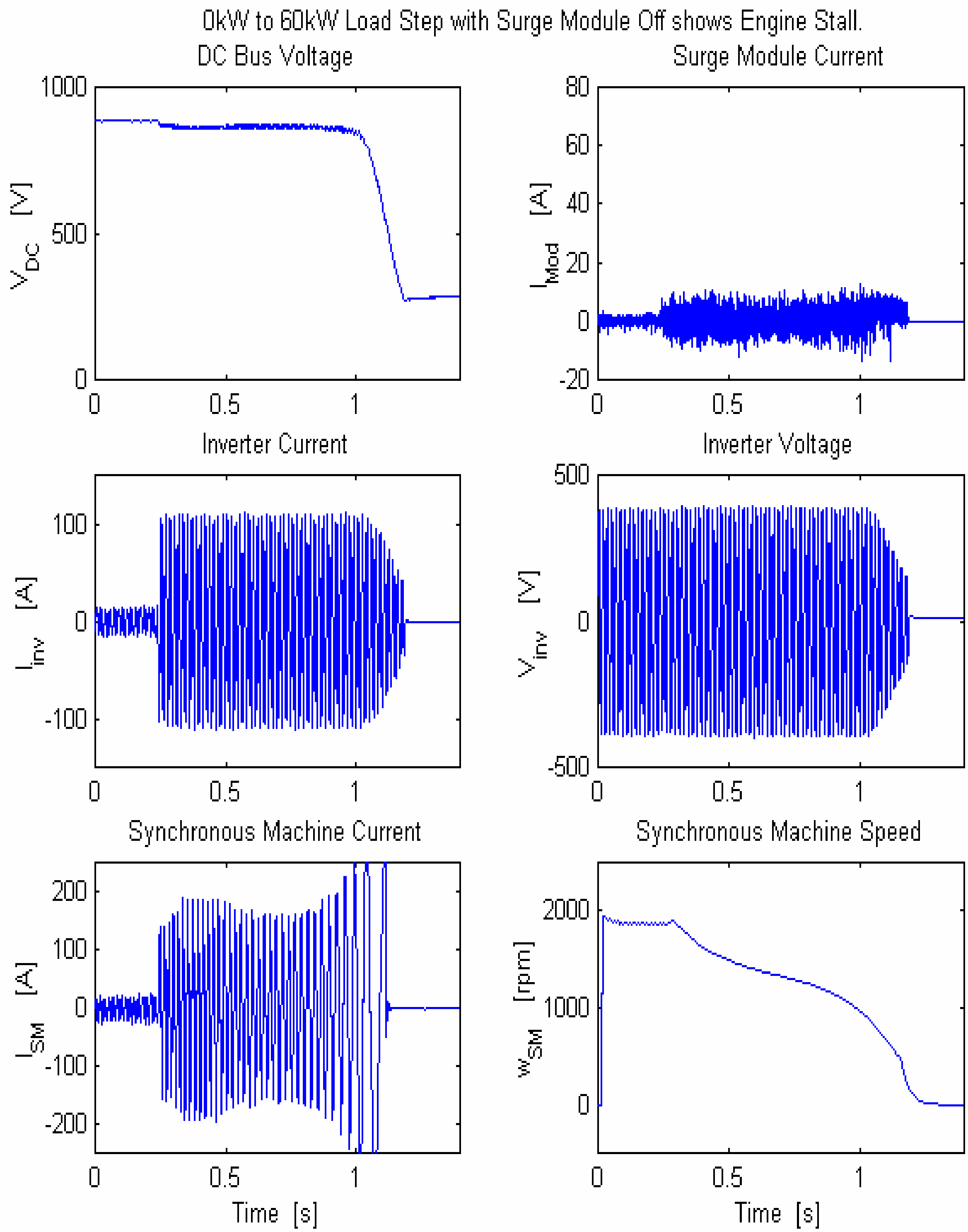

0kW to 60kW Load Step with Surge Module Off shows Engine Stall.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 11.

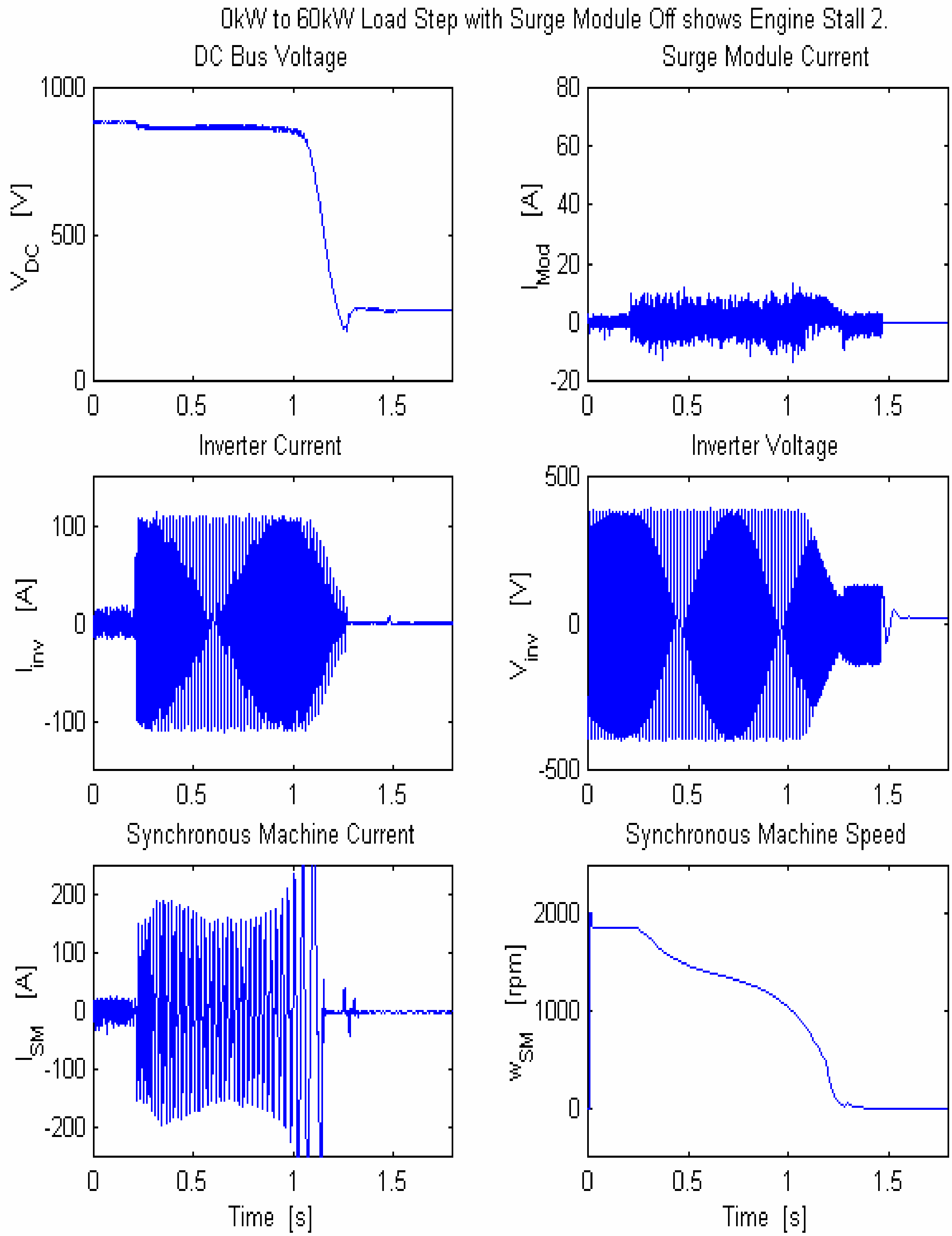

0kW to 60kW Load Step with Surge Module Off shows Engine Stall 2.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 12.

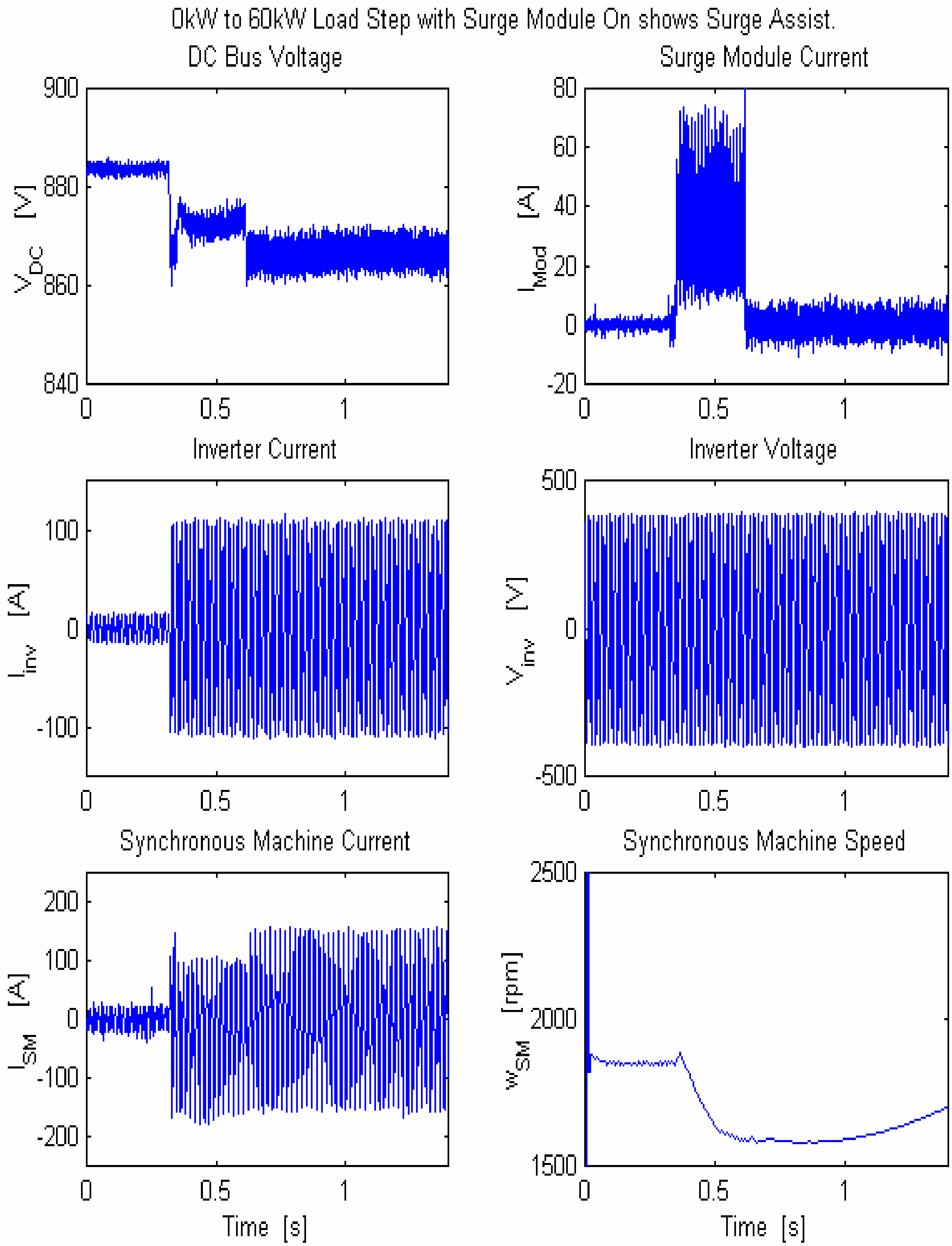

0kW to 60kW Load Step with Surge Module On shows Surge Assist.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_{DC} [V]
I_{Mod} [A]
I_{inv} [A]
V_{inv} [V]
I_{SM} [A]
w_{SM} [rpm]
Time [s]
Time [s]

Figure 13.

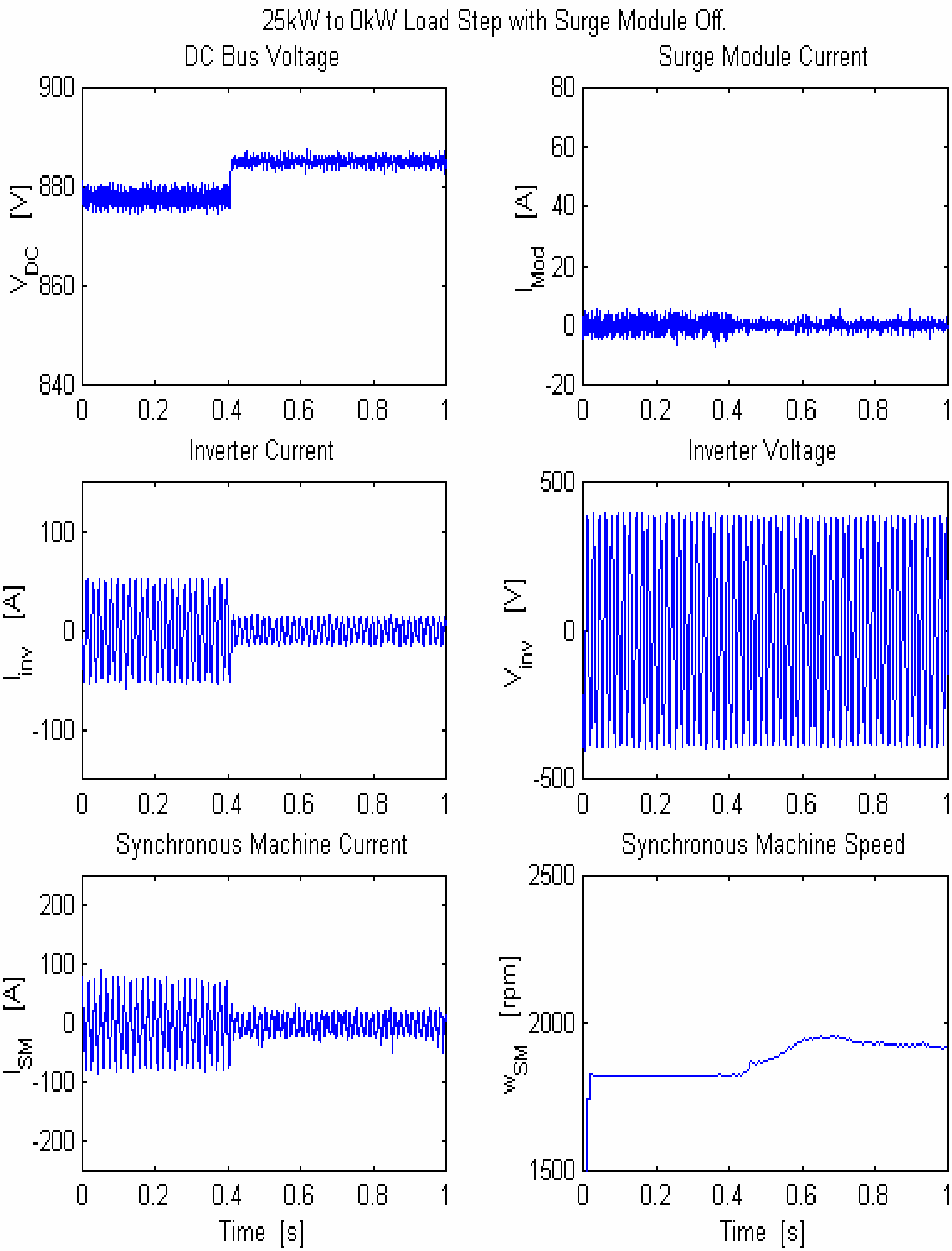

25kW to 0kW Load Step with Surge Module Off.
DC Bus Voltage
V_{DC} [V]
900
880
860
840
0
0.2
0.4
0.6
0.8
1
Surge Module Current
I_{Mod} [A]
80
60
40
20
0
-20
0
0.2
0.4
0.6
0.8
1
Inverter Current
I_{inv} [A]
100
0
-100
0
0.2
0.4
0.6
0.8
1
Inverter Voltage
V_{inv} [V]
500
0
-500
0
0.2
0.4
0.6
0.8
1
Synchronous Machine Current
I_{SM} [A]
200
100
0
-100
-200
0
0.2
0.4
0.6
0.8
1
Time [s]
Synchronous Machine Speed
w_{SM} [rpm]
2500
2000
1500
0
0.2
0.4
0.6
0.8
1
Time [s]

Figure 14.

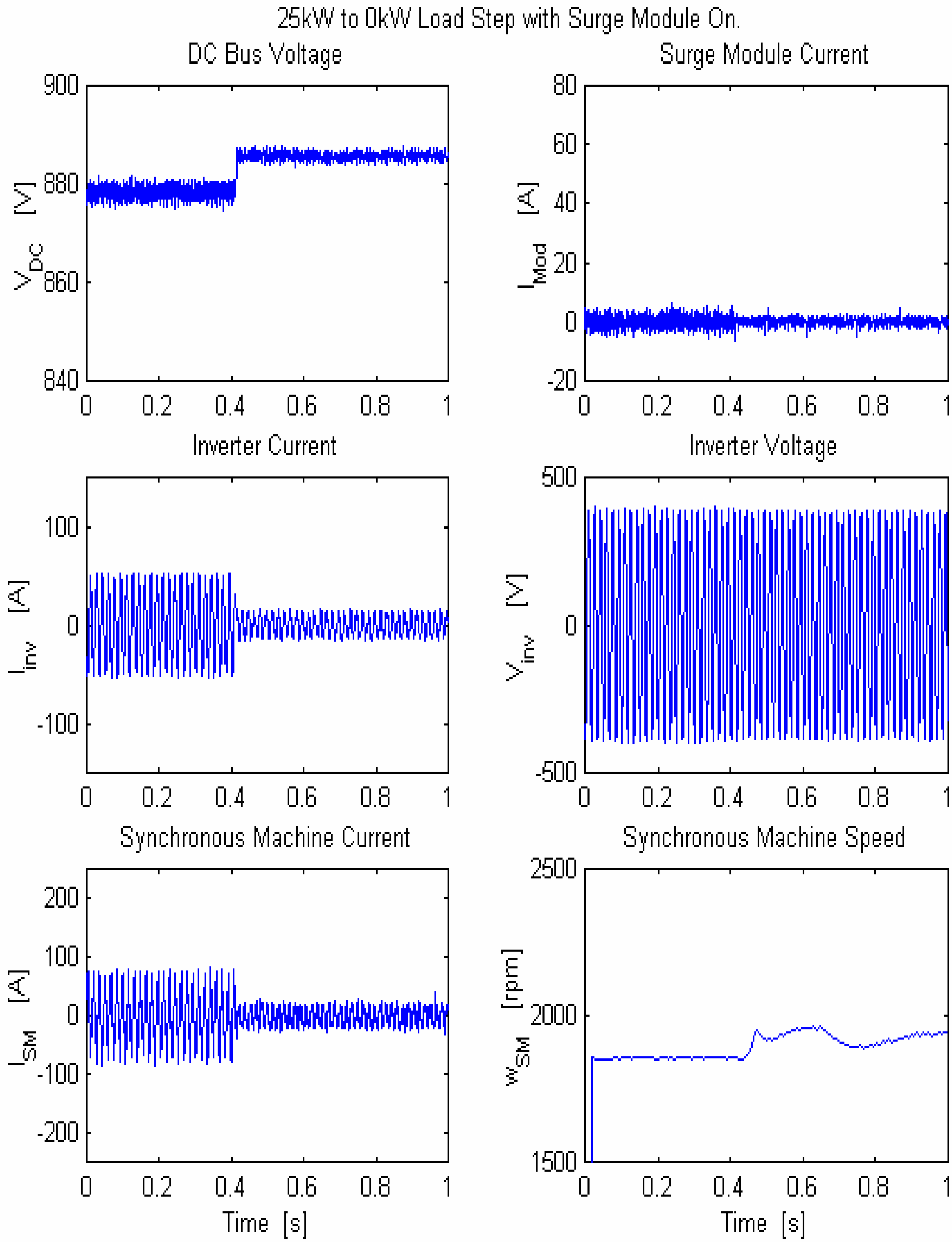

25kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 15.

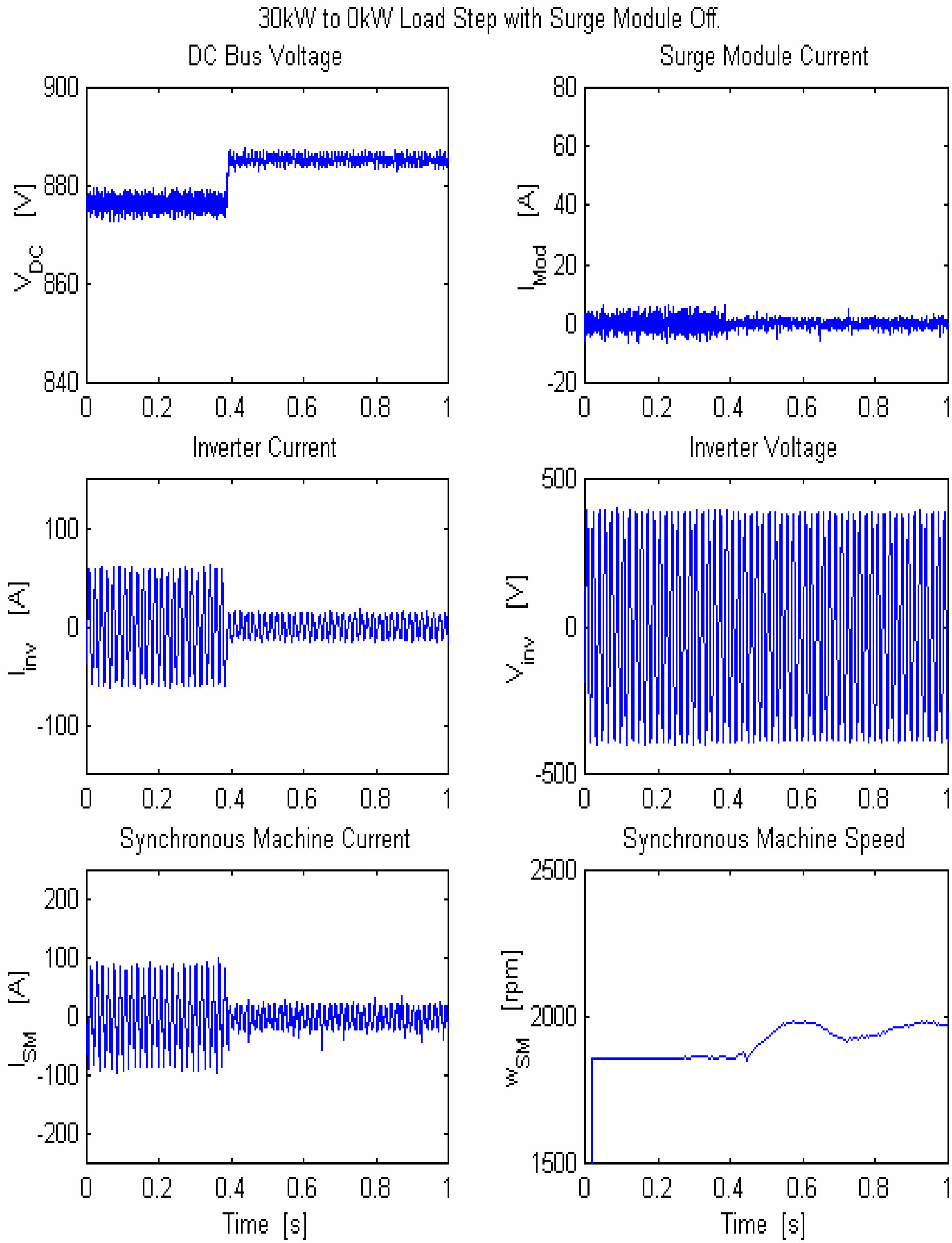

30kW to 0kW Load Step with Surge Module Off.
DC Bus Voltage
V_{DC} [V]
900
880
860
840
0 0.2 0.4 0.6 0.8 1
Surge Module Current
I_{Mod} [A]
80
60
40
20
0
-20
0 0.2 0.4 0.6 0.8 1
Inverter Current
I_{inv} [A]
100
0
-100
0 0.2 0.4 0.6 0.8 1
Inverter Voltage
V_{inv} [V]
500
0
-500
0 0.2 0.4 0.6 0.8 1
Synchronous Machine Current
I_{SM} [A]
200
100
0
-100
-200
0 0.2 0.4 0.6 0.8 1
Time [s]
Synchronous Machine Speed
w_{SM} [rpm]
2500
2000
1500
0 0.2 0.4 0.6 0.8 1
Time [s]

Figure 16.

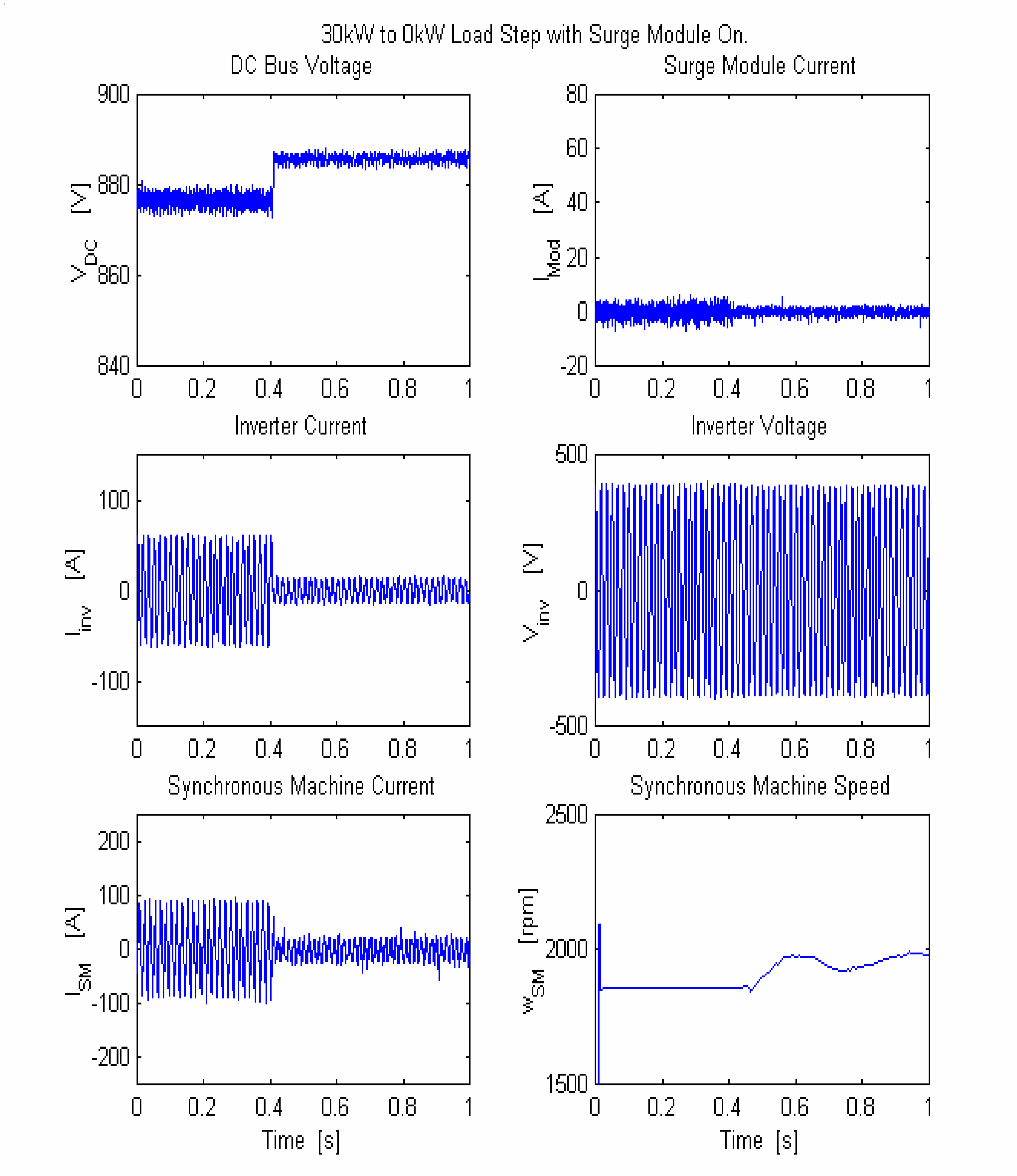

30kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 17.

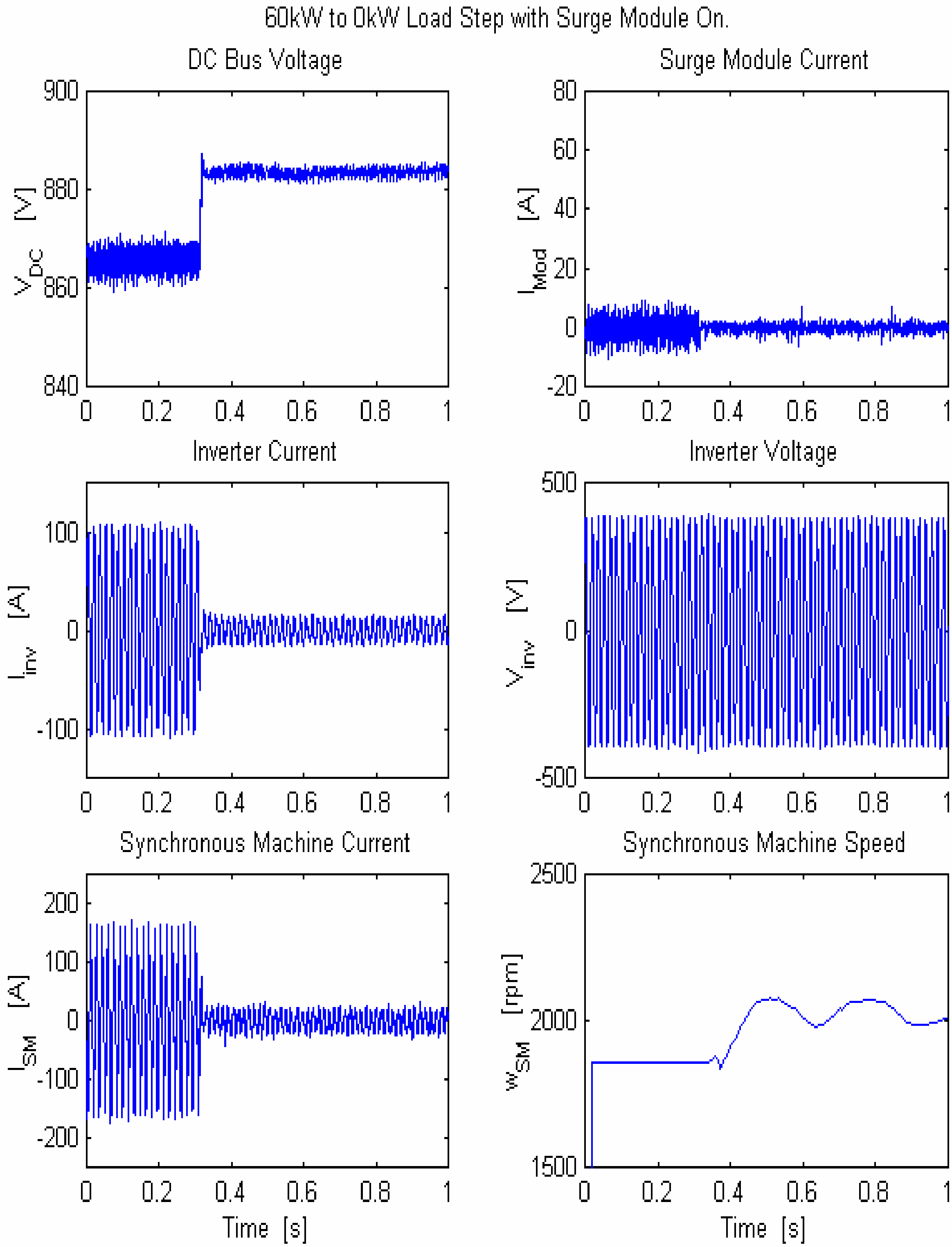

60kW to 0kW Load Step with Surge Module On.
DC Bus Voltage
Surge Module Current
Inverter Current
Inverter Voltage
Synchronous Machine Current
Synchronous Machine Speed
V_DC [V]
I_Mod [A]
I_inv [A]
V_inv [V]
I_SM [A]
w_SM [rpm]
Time [s]
Time [s]

Figure 18.