भारत सरकार
Government of India
केन्द्रीय विद्युत प्राधिकरण
Central Electricity Authority
प्रणाली योजना एवं परियोजना मूल्यांकन प्रभाग
System Planning & Project Appraisal Division
सेवा भवन, आर. के. पुरम, नई दिल्ली-110066
Sewa Bhawan, R. K. Puram, New Delhi-110066
वेबसाइट / **Website: www.cea.nic.in**

[ISO: 9001:2008]

No. 200/10/2013-SP&PA/ 1287-1339.

Date : 08.08.2013

To,

As per list attached

Sub.:- Combined meetings of the Standing Committees on Power System Planning – Additional Agenda

Sir,

This is in continuation to our earlier letter of even no. dated 02.08.2013, the additional agenda with respect to the study report on Dynamic Compensation at 13 locations in WR,ER,NR and SR as received from POWERGRID is available at CEA website : www.cea.nic.in (path to access – Home Page -Wing specific document /power system related reports / standing committee on power system planning).

Yours faithfully,

(B.K. Sharma) 8/8/2013
Director (SP&PA)

1.0 **Proposal for Dynamic Compensations in Northern Region, Eastern Region, Western Region and Southern Region.**

1.1 In the previous standing committee meeting of NR, ER, WR and SR Static Var Compensators (SVC) / STATCOMs of ± 400 MVAR was agreed at 13 locations. It was also agreed that the choice of SVCs / STATCOMs would be evaluated through relevant studies for technology selection.

1.2 POWERGRID has informed that in order to finalize the technology, rating / sizing of dynamic compensation for Indian grid condition, they have interacted with various manufactures and utilities. POWERGRID has appointed Dr. Narain G. Hingorani an expert in the field of HVDC, FACTS, Power System as consultant and had detailed deliberation on the technological and rating aspects of requirement of dynamic compensation. The conclusion of deliberation is given below:

a) For dynamic compensation, STATCOM is preferred over SVCs in view of its faster response, requirement of less space and above all its state-of-the-art technology.

b) The STATCOMs may be combined with mechanically switched Reactors & Capacitors controlled by STATCOM controller. The STATCOM would be primarily for dynamic compensation while the mechanically switched reactors / capacitors would be for reactive compensation under steady state.

1.3 Accordingly, POWERGRID has carried out studies comparing STATCOM with SVC. Based on the studies , STATCOMs has been proposed to meet the dynamic reactive compensation requirements at following sub-stations:

Sl. No.	**Location**	**Dynamic Compensation (STATCOM)**	**Mechanically Switched Compensation (MVAR)**	
			Reactor	**Capacitor**
Northern Region:				
1.	Nalagarh	± 200 MVAR	2 x 125	2 x 125
2.	New Lucknow	± 300 MVAR	2 x 125	1 x 125
Western Region:				
3.	Solapur	± 300 MVAR	2 x 125	1 x 125
4.	Gwalior	± 200 MVAR	2 x 125	1 x 125
5.	Satna	± 300 MVAR	2 x 125	1 x 125
6.	Aurangabad (PG)	± 300 MVAR	2 x 125	1 x 125
Southern Region:				
7.	Hyderabad (PG)	± 200 MVAR	2 x 125	1 x 125
8.	Udumalpet	± 200 MVAR	2 x 125	1 x 125
9.	Trichy	± 200 MVAR	2 x 125	1 x 125
Eastern Region:				
10.	Rourkela	± 300 MVAR	2 x 125	-
11.	Kishanganj	± 200 MVAR	2 x 125	-
12.	Ranchi (New)	± 300 MVAR	2 x 125	-
13.	Jeypore	± 200 MVAR	2 x 125	2 x 125

1.4 The study report is enclosed. POWERGRID to make a presentation on the study.

1.5 Members may deliberate.

Studies for Dynamic Compensation (STATCOM) requirements

1.0 Background

In the recent past, the dynamic compensation in the form of Static Var Compensator (SVC) was agreed Standing Committee for Power System Planning of various regions which include NR, ER, WR and SR.

Further analysis has been carried out in order to finalise the technology, size etc which would be suitable to Indian Grid conditions. In this process, a series of meetings/discussions with various manufacturers and utilities were undertaken in order to get the insight of the technology along with their opinion/feedback.

To further assist on the above, Dr. Narain G. Hingorani, a consultant of International repute in the field of HVDC, FACTS, Power Electronics, Power Systems and T&D was appointed. After detailed deliberation with him, the following conclusions have been arrived at :

- For dynamic compensation, STATCOM is preferred over SVCs in view of its faster response, requirement of less space and above all its state-of-the-art technology.

- The STATCOMs may be combined with mechanically switched Reactors & Capacitors controlled by STATCOM controller. The STATCOM would be primarily for dynamic compensation while the mechanically switched reactors / capacitors would be for reactive compensation under steady state.

Based on the above, studies were carried out for STATCOM as compared to SVC. The details of the studies are given below:

2.0 Dynamic Compensation

The dynamic compensation facilitates enhanced voltage stability by providing reactive power support to the power system. **Voltage stability** is the ability of a system to maintain steady acceptable voltages at all the buses in the system at all conditions. The ability to transfer reactive power from production source to consumption areas during steady-state operating conditions is a major problem of voltage stability. A system mainly enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition cause a progressive and uncontrollable decline in voltage.

This situation of Voltage instability can be avoided by: (a) appropriate load shedding on the consumer network; (b) on load tap changers; (c) adequate reactive compensation (series and/or shunt). Therefore, the key contributing factor in voltage collapse is the rapid and progressive loss of voltage controllability due to reactive limit violations.

2.1 Static Var Compensator (SVC)

A Static Var Compensator (SVC) is a parallel combination of controlled shunt reactor and capacitor to regulate the voltage at a bus, where it is installed. The arrangement shown in Figure–1 below, is that of a controlled shunt reactor in which thyristors are in series with a reactor that directly control the current flow through the reactor. The effect of controlled firing of the thyristors is to control the effective fundamental frequency admittance of the thyristor-reactor unit as seen from its high-voltage terminals.

Figure–2 below shows the arrangement of combination of controlled reactor in parallel to shunt capacitor.

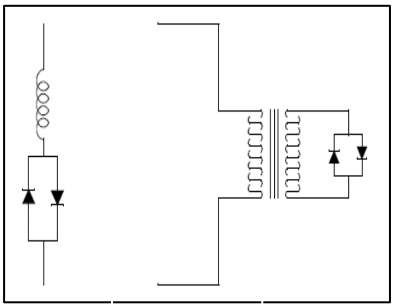


Figure-1

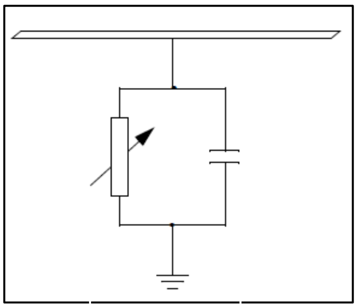


Figure-2

- With the reactor turned "off" through thyristor switching, the installation is a shunt capacitor that will supply reactive power to the system.

- The reactor may be turned "on" in controlled fashion to absorb reactive power of varying quantum, thereby the effective value of reactive VARs absorbed from the system or supplied to the system can be controlled.

In addition SVC also helps in Steady State voltage control, Dynamic voltage control during disturbance, reduction of temporary & dynamic overvoltage, improving transient stability and damping of power oscillations.

2.2 Static Synchronous Compensator (STATCOM)

A Static Synchronous Compensator (STATCOM) is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; on the other hand, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of an SVC, mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

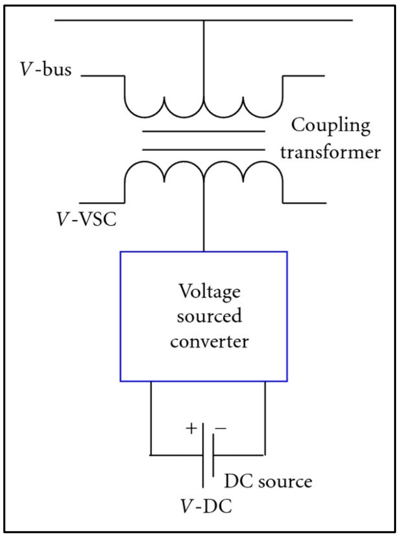


Figure-3

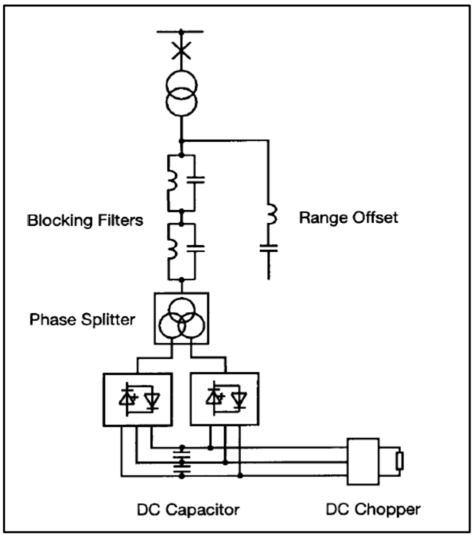


Figure-4

Figure-3 & 4 shows STATCOMs principal diagram and single line diagram respectively.

2.3 STATCOM v/s SVC

Figure-5 & 6 shows VI characteristic of SVC & STATCOMs respectively

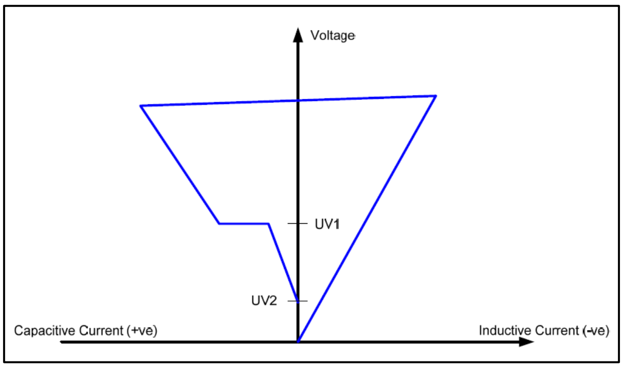


Figure-5

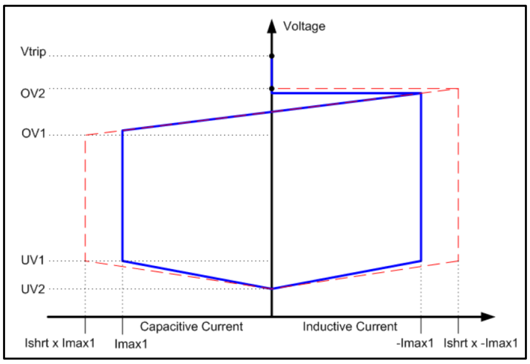


Figure-6

Further advantages of STATCOM as compared to an SVC are

- The reactive power compensation provided by the STATCOM is more than the SVC because at a low voltage limit, the reactive power drops off as the square of the voltage for the SVC, where Mvar=f(BV^2), but drops off linearly with the STATCOM, where Mvar=f(VI). This makes the reactive power controllability of the STATCOM superior to that of the SVC, particularly during times of system distress.

  When the system voltage drops sufficiently due to loss of parallel line to force the STATCOM output current to its ceiling, its maximum reactive output current will not be affected by the voltage magnitude. Therefore, it exhibits constant current characteristic. In contrast the SVC's MVA output is proportional to the square of the voltage magnitude. Thus the capacitive reactive power decreases, just when needed. This is major disadvantage of SVC.

- STATCOM at reduced voltage can still inject maximum current, whereas SVC current capability reduces in proportion to voltage. As a result, STATCOM has superior dynamic response and for comparison, STATCOM may be rated for 75% of SVC rating for same performance in response to line fault.

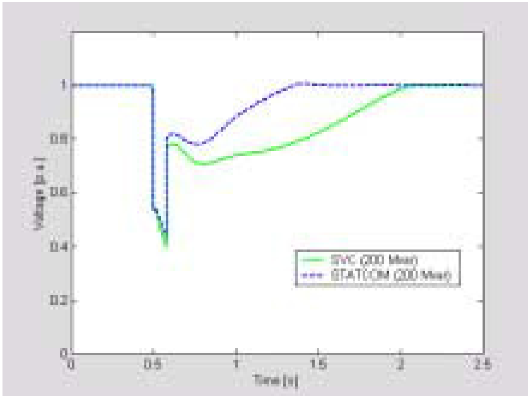


Figure-7 : Voltage variation with SVC & STATCOM

Analytical examination reveals that a STATCOM stability loop is more robust than an SVC with respect to the variation in the network capacity; i.e. for loss of a parallel path. STATCOM also has a quicker response time (step response of 8 ms to 30ms).

- Active power control is possible with a STATCOM (with optional energy storage on dc circuit). This could further help with system stability control.

- SVCs with TCR need harmonic filters at least 5th-7th, 11th-13th and high pass. The capacitive filter rating is in the range of 30–50% of the TCR size. Filter is not switched and therefore the TCR is offset by 30-50% in capacitive direction. Also low order harmonic filters, depending on the system impedance, may lead to harmonic resonance in the field and may need field modifications. This is also a major disadvantage of TCR. On the other hand, Thyristor Switched Reactors (TSRs) do not need filters but may not be as helpful in damping system oscillations as a continuously variable TCR. Therefore along with TSRs and TSCs, a TCR of a size somewhat greater than each TSR and TSC is still required.

  With Thyristors TCR has no current limitation for over-voltage once the reactor is fully in. The STATCOM on the other hand has to be designed for the maximum allowable temporary over voltage in the system.

- No potential for creating a resonance point, as no capacitor banks or reactors are required to generate the reactive power. For modern STATCOMs, only a small blocking filter is required and do not need field modifications.

- Requires smaller installation space as no capacitors or reactors are required to generate Mvar, minimal or no filtering, and the availability of high capacity power semiconductor devices.

- Designs of systems of equal dynamic ranges have shown the STATCOM to be as much as 1/3 the area and 1/5 the volume of an SVC.

- The modular design of the STATCOM allows for high availability (i.e., one or more modules of the STATCOM can be out-of-service without the loss of the entire compensation system). Standardized STATCOMs of +/-50 MVAR can be delivered in containers, fully tested in the factory. Several of these units can be configured as a fully parallel operating system. STATCOMS are generally expandable and re-locatable.

- STATCOM can balance the voltages, i.e. decrease negative sequence voltage.

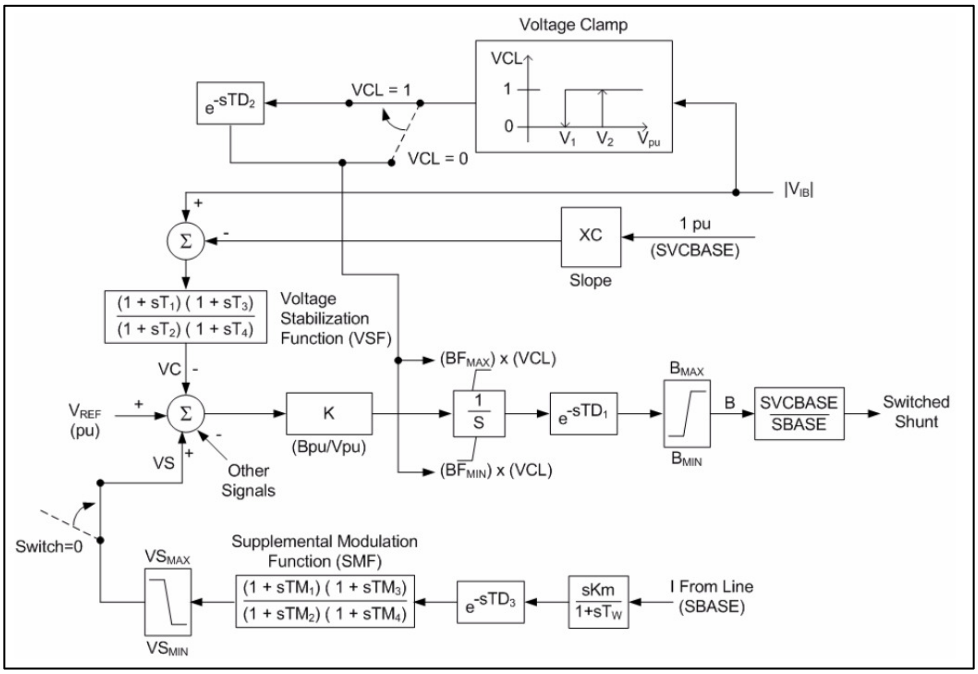
- Due to higher device stresses in the capacitive direction, the capacitive rating may be about 10% less than its inductive rating. STATCOM can be offset with TSC or MSC or TSR or MSR as needed.

3.0 System Studies for Static Synchronous Compensator (STATCOM)

The system studies were performed considering all India network corresponding to 2016-17 time frame peak load conditions

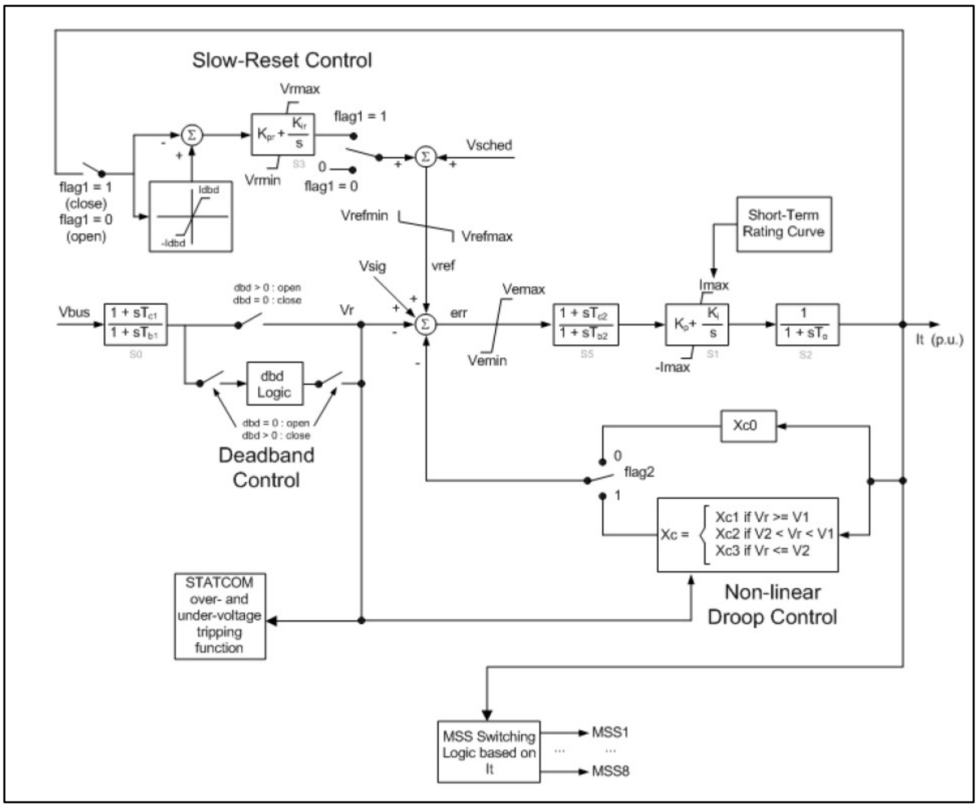
3.1 SVC model considered in the Study:

Following generic SVC model (CHSVCT) was taken in the dynamic study:



3.2 STATCOM model considered in the Study:

Following STATCOM model (SVSMO3) was taken in the dynamic study:



3.3 Voltage Profile Analysis for Candidate Locations:

The voltage profile analysis has been carried out for the 400kV inter-state transmission system (ISTS) buses in Northern, Western, Southern and Eastern Region where the SVC were agreed. The comparative analysis of the voltages and MVAR injection at each location with SVC and STATCOM both for peak and off-peak conditions are given in respective Exhibits.

Sl. No.	Bus Name	Short Circuit (GVA/kA)	Peak Dynamic results Exhibit No.		Off-peak Dynamic results Exhibit No.	
			Voltage	MVAR	Voltage	MVAR
Northern Region:						
1.	Nalagarh	19.3 / 27.8	1-P(a)	1-P(b)	1-OP(a)	1-OP(b)
2.	New Lucknow	34.6 / 50.0	2-P(a)	2-P(b)	2-OP(a)	2-OP(b)
Western Region:						
3.	Solapur	24.0 / 34.6	3-P(A)	3-P(B)	3-O(A)	3-O(B)
4.	Gwalior	16.6 / 24.0	4-P(A)	4-P(B)	4-O(A)	4-O(B)
5.	Satna	27.2 / 39.3	5-P(A)	5-P(B)	5-O(A)	5-O(B)
6.	Aurangabad (PG)	30.0 / 43.3	6-P(A)	6-P(B)	6-O(A)	6-O(B)
Southern Region:						
7.	Hyderabad (PG)	18.4 / 26.5	7-P(a)	7-P(b)	7-OP(a)	7-OP(b)
8.	Udumalpet	19.4 / 28.0	8-P(a)	8-P(b)	8-OP(a)	8-OP(b)
9.	Trichy	12.5 / 18.0	9-P(a)	9-P(b)	9-OP(a)	9-OP(b)

Eastern Region:						
10.	Jeypore	10 / 14.4	10-P(a)	10-P(b)	10-O(a)	10-O(b)
11.	Kishanganj	20.2 / 29.2	11-P(a)	11-P(b)	11-O(a)	11-O(b)
12.	Ranchi (New)	32.2 / 46.5	12-P(a)	12-P(b)	12-O(a)	12-O(b)
13.	Rourkela	25.5 / 36.8	13-P(a)	13-P(b)	13-O(a)	13-O(b)

The study results show improvement in voltage profile with STATCOMs compared to that with the SVCs.

4.0 Conclusion

For optimisation of dynamic compensation, hybrid solutions of STATCOM along with mechanically switched capacitors & reactors controlled by STATCOM controller has been considered. The STATCOM would be primarily for dynamic compensation while the mechanically switched reactors / capacitors would be for reactive compensation under steady state. Accordingly, in place of ± 400 MVAR dynamic compensation in the form of SVC approved earlier, a variable component of ±200 MVAR to ±300 MVAR has been considered while the balance reactive compensation has been provided through Mechanically Switched Reactors & Capacitors.

Based on the above considerations and studies, it is proposed that following STATCOMs may be considered to meet the dynamic reactive compensation requirements at following sub-stations:

Sl. No.	Location	Dynamic Compensation (STATCOM)	Mechanically Switched Compensation (MVAR)	
			Reactor	Capacitor
Northern Region:				
14.	Nalagarh	± 200 MVAR	2 x 125	2 x 125
15.	New Lucknow	± 300 MVAR	2 x 125	1 x 125
Western Region:				
16.	Solapur	± 300 MVAR	2 x 125	1 x 125
17.	Gwalior	± 200 MVAR	2 x 125	1 x 125
18.	Satna	± 300 MVAR	2 x 125	1 x 125
19.	Aurangabad (PG)	± 300 MVAR	2 x 125	1 x 125
Southern Region:				
20.	Hyderabad (PG)	± 200 MVAR	2 x 125	1 x 125
21.	Udumalpet	± 200 MVAR	2 x 125	1 x 125
22.	Trichy	± 200 MVAR	2 x 125	1 x 125
Eastern Region:				
23.	Rourkela	± 300 MVAR	2 x 125	-
24.	Kishanganj	± 200 MVAR	2 x 125	-
25.	Ranchi (New)	± 300 MVAR	2 x 125	-
26.	Jeypore	± 200 MVAR	2 x 125	2 x 125

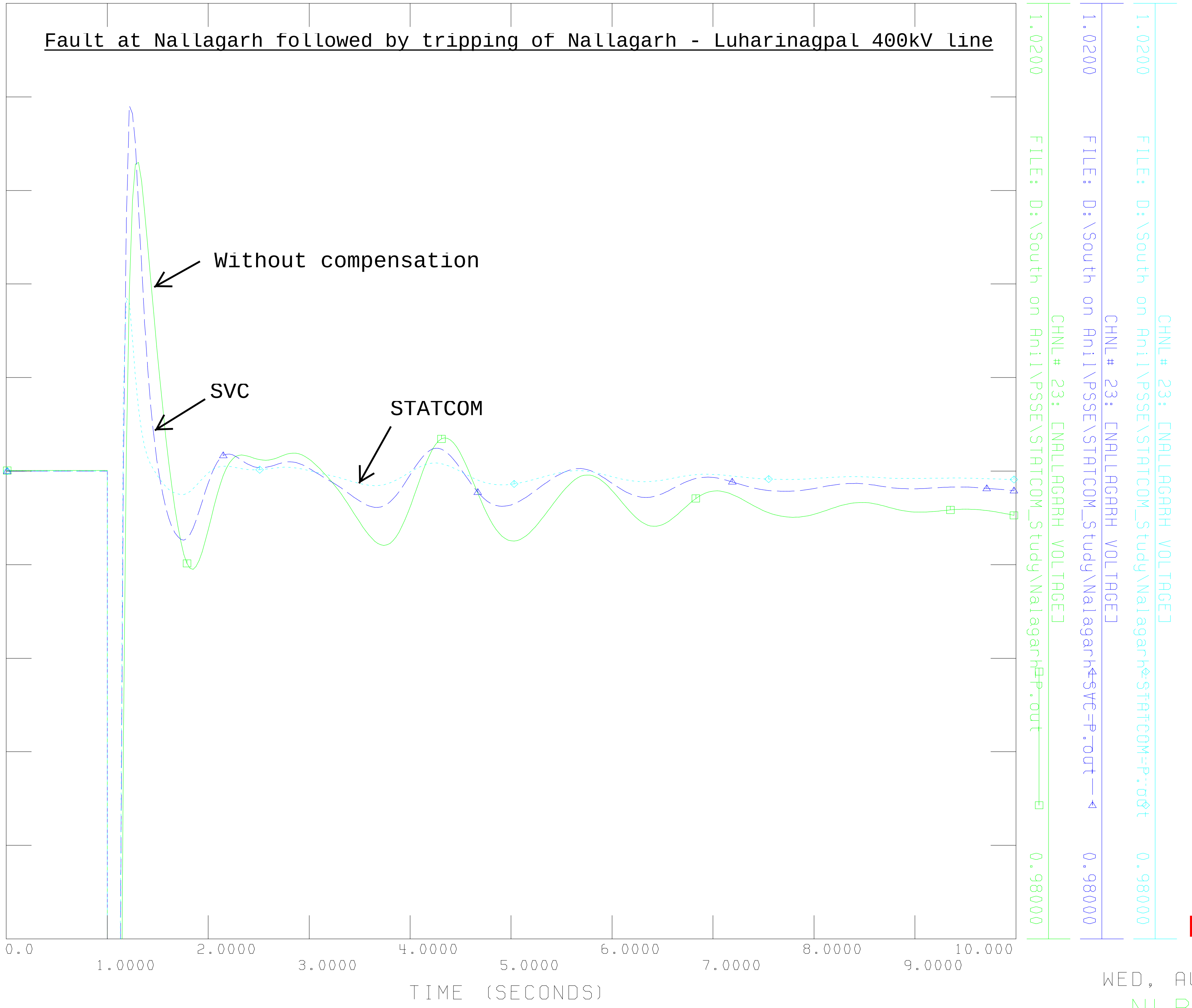


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EXHIBIT-1-P(a)

WED, AUG 07 2013 22:39

NLRGH V - PEAK

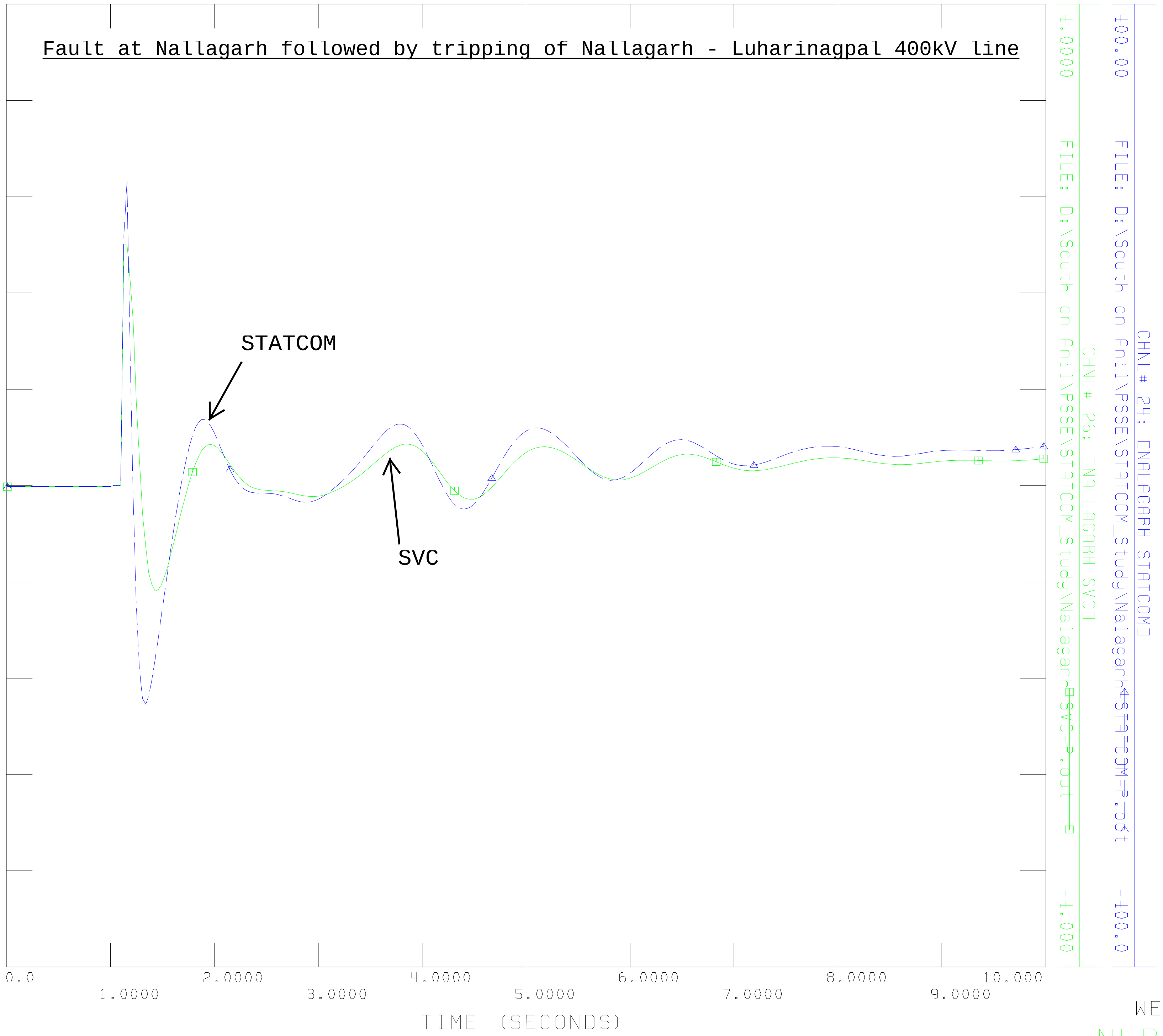

EXHIBIT-1-P(b)

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NLRGH MVAR - PEAK

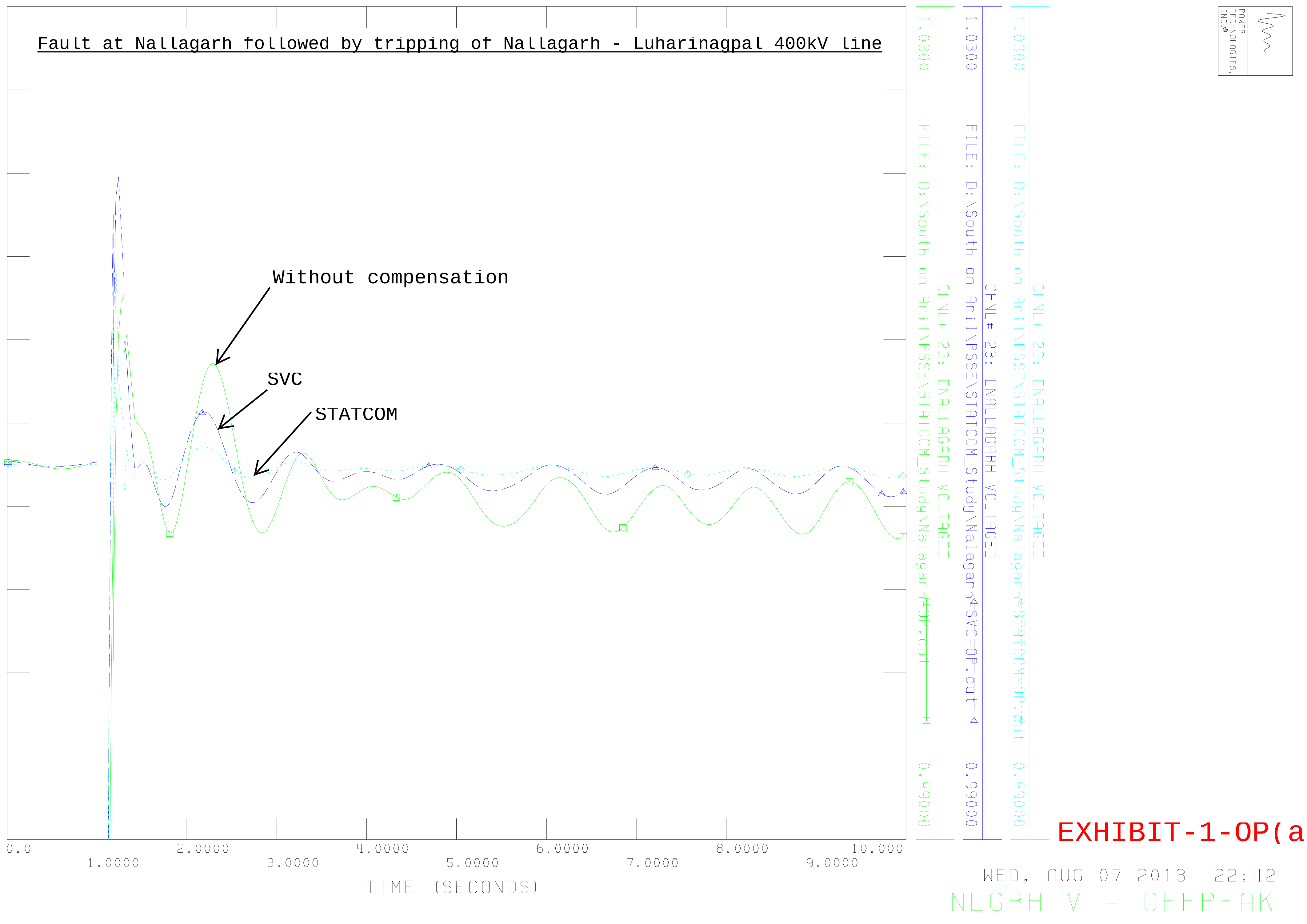


EXHIBIT-1-OP(a)

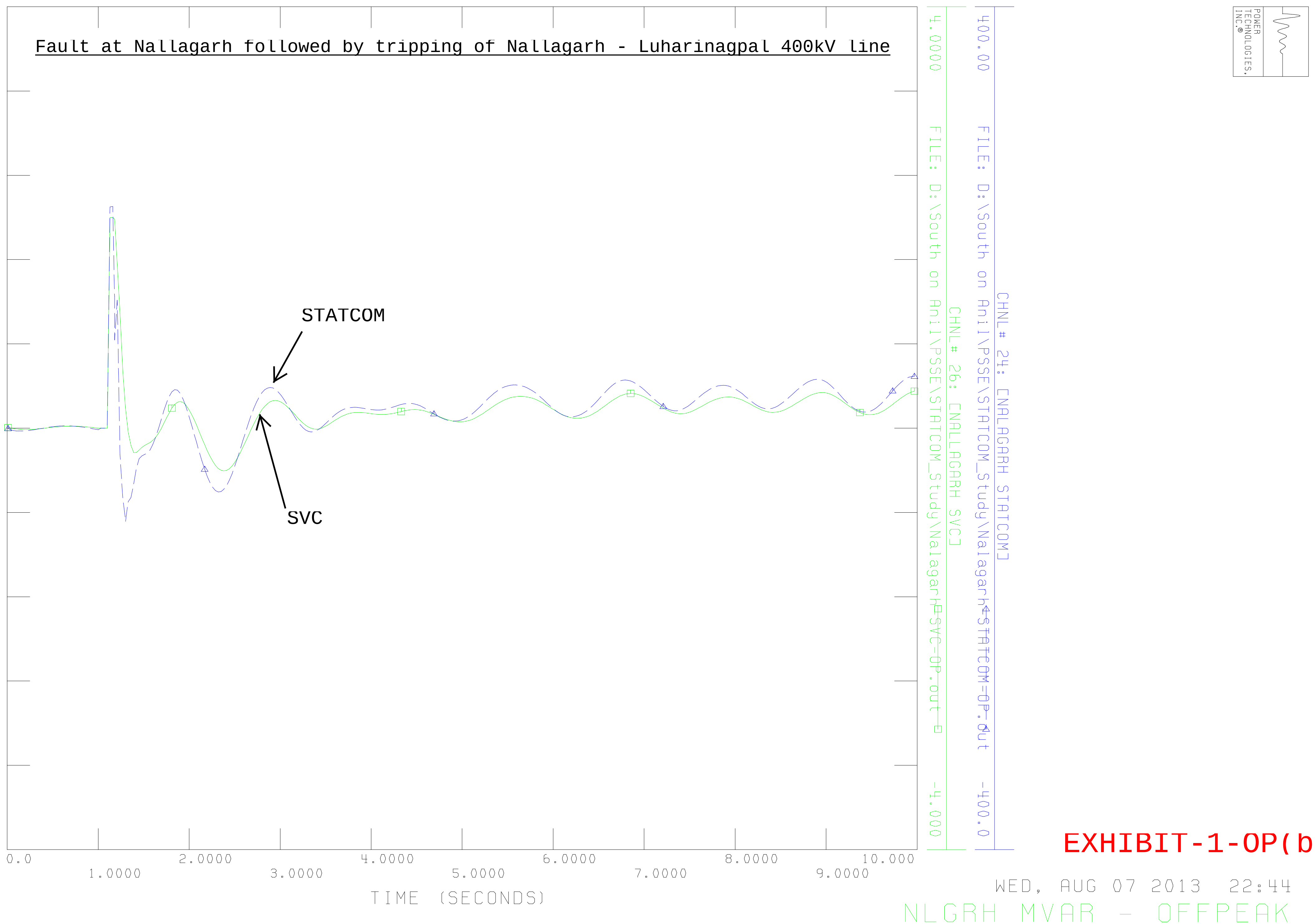
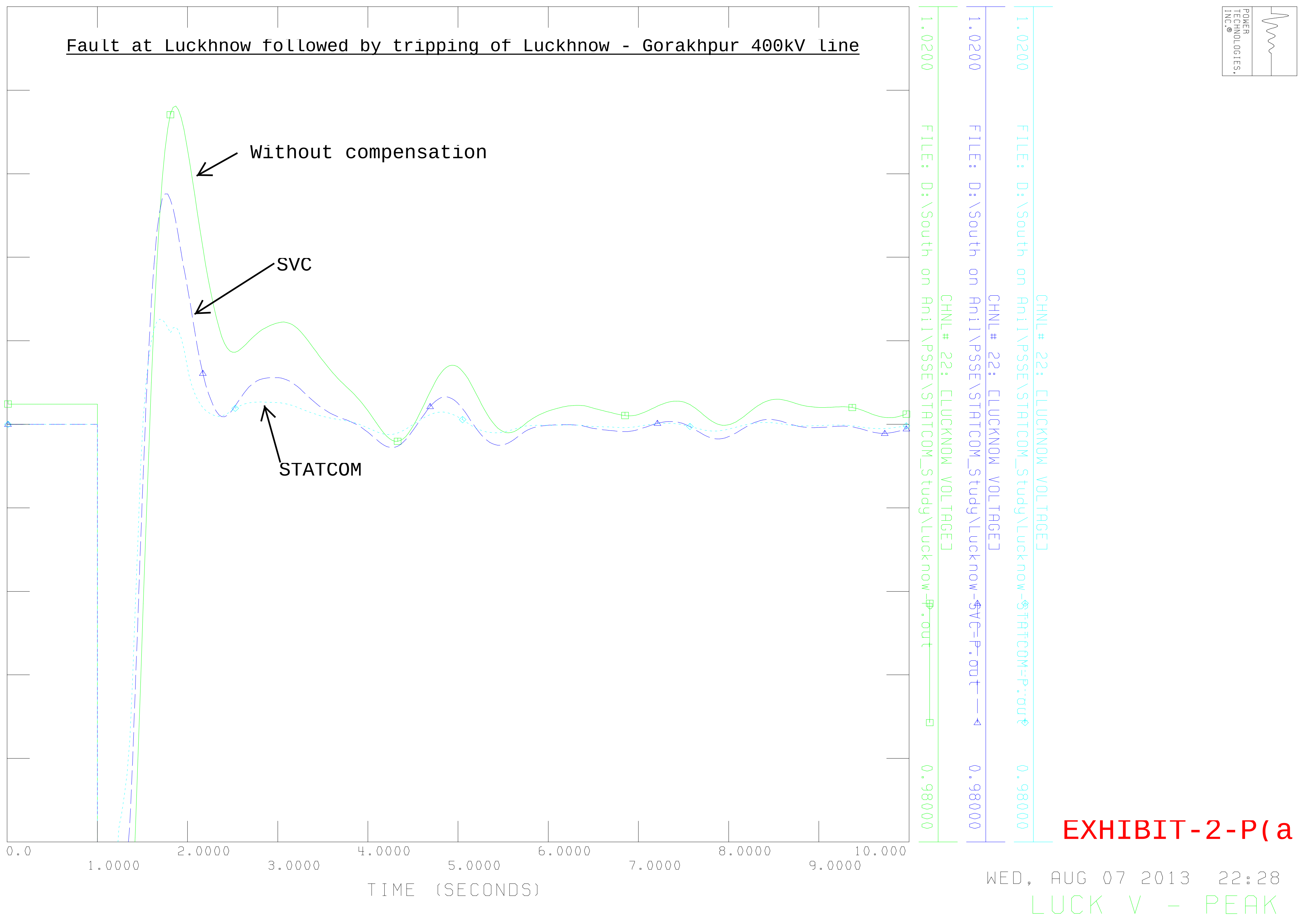


EXHIBIT-1-OP(b)


Fault at Luckhnow followed by tripping of Luckhnow - Gorakhpur 400kV line
Without compensation
SVC
STATCOM
0.0
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
9.0000
10.000
TIME (SECONDS)
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1.0200
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CHNL# 22: [LUCKNOW VOLTAGE]
0.98000
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POWER TECHNOLOGIES, INC.®
WED, AUG 07 2013 22:28
LUCK V - PEAK

EXHIBIT-2-P(a)

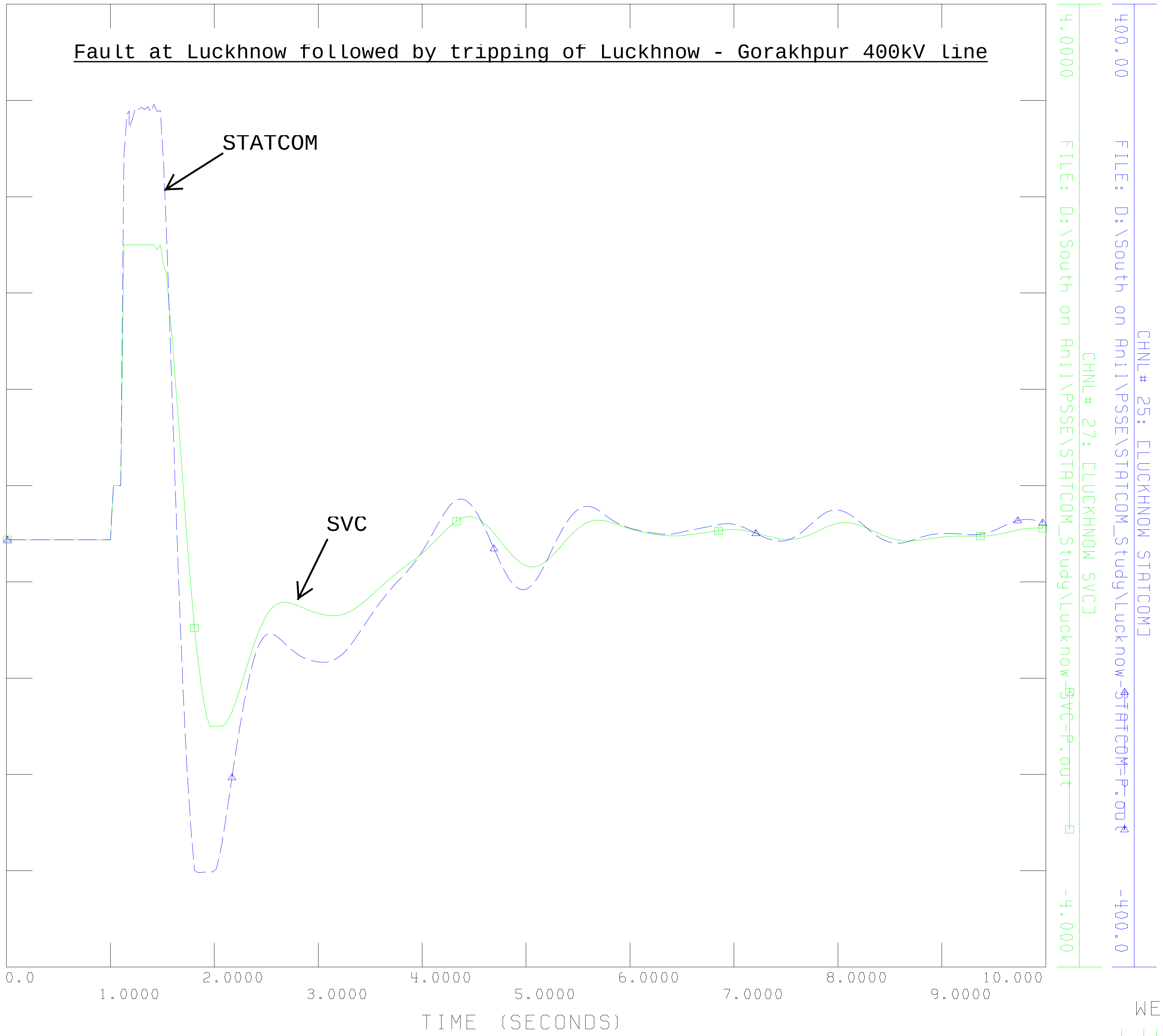


EXHIBIT-2-P(b)

WED, AUG 07 2013 22:30

LUCK MVAR - PEAK

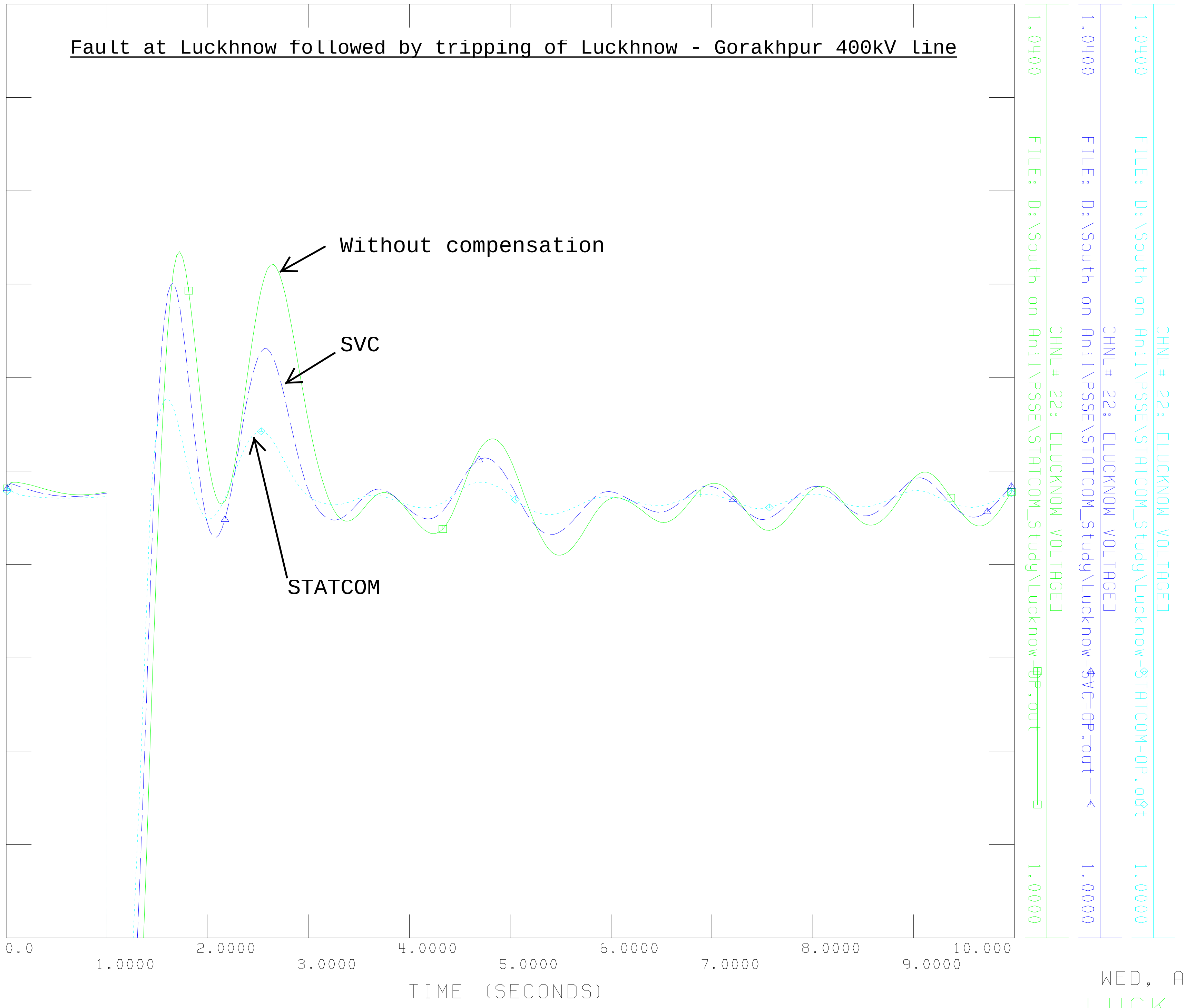


EXHIBIT-2-OP(a)

WED, AUG 07 2013 22:37

LUCK V - OFFPEAK

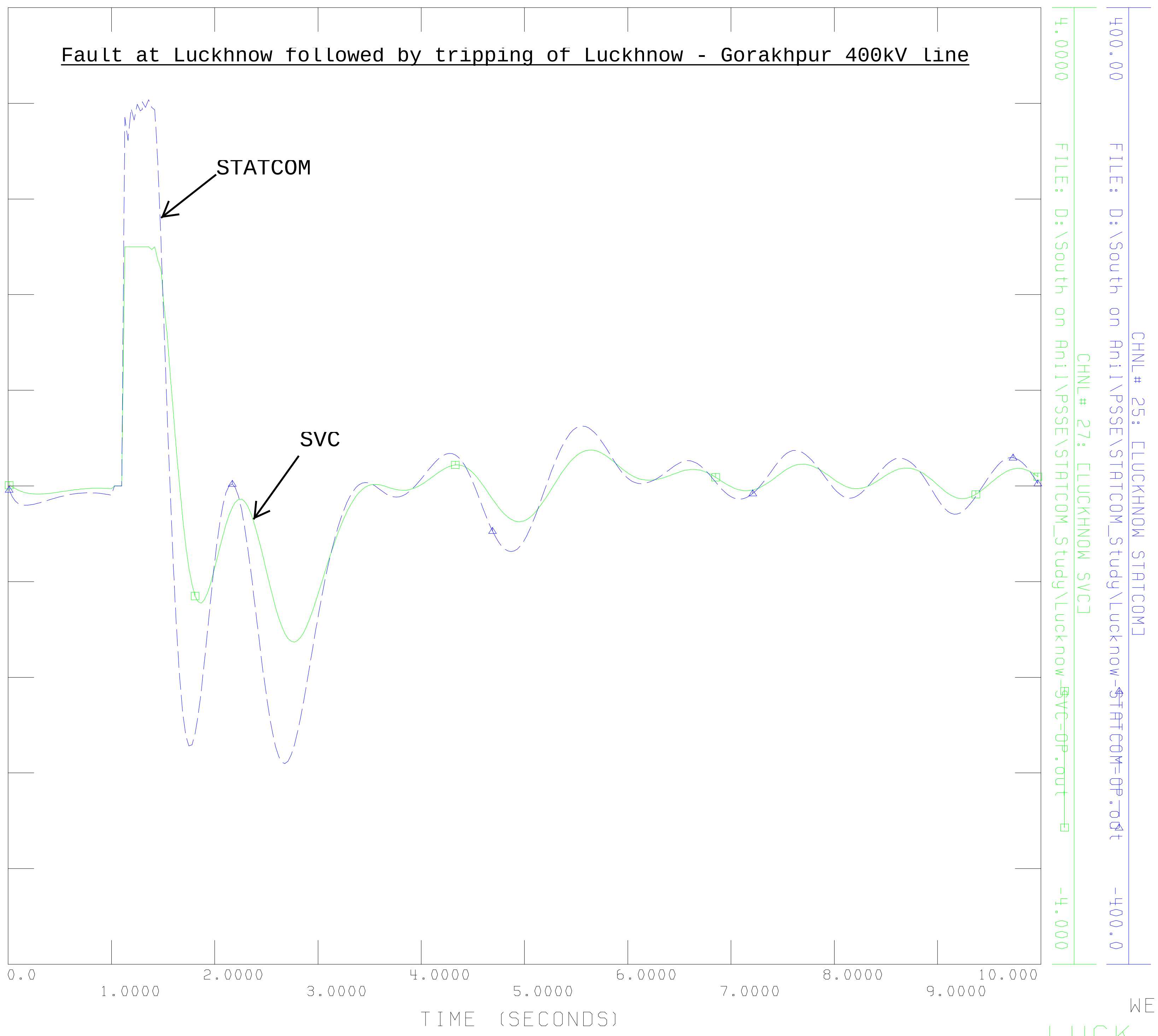
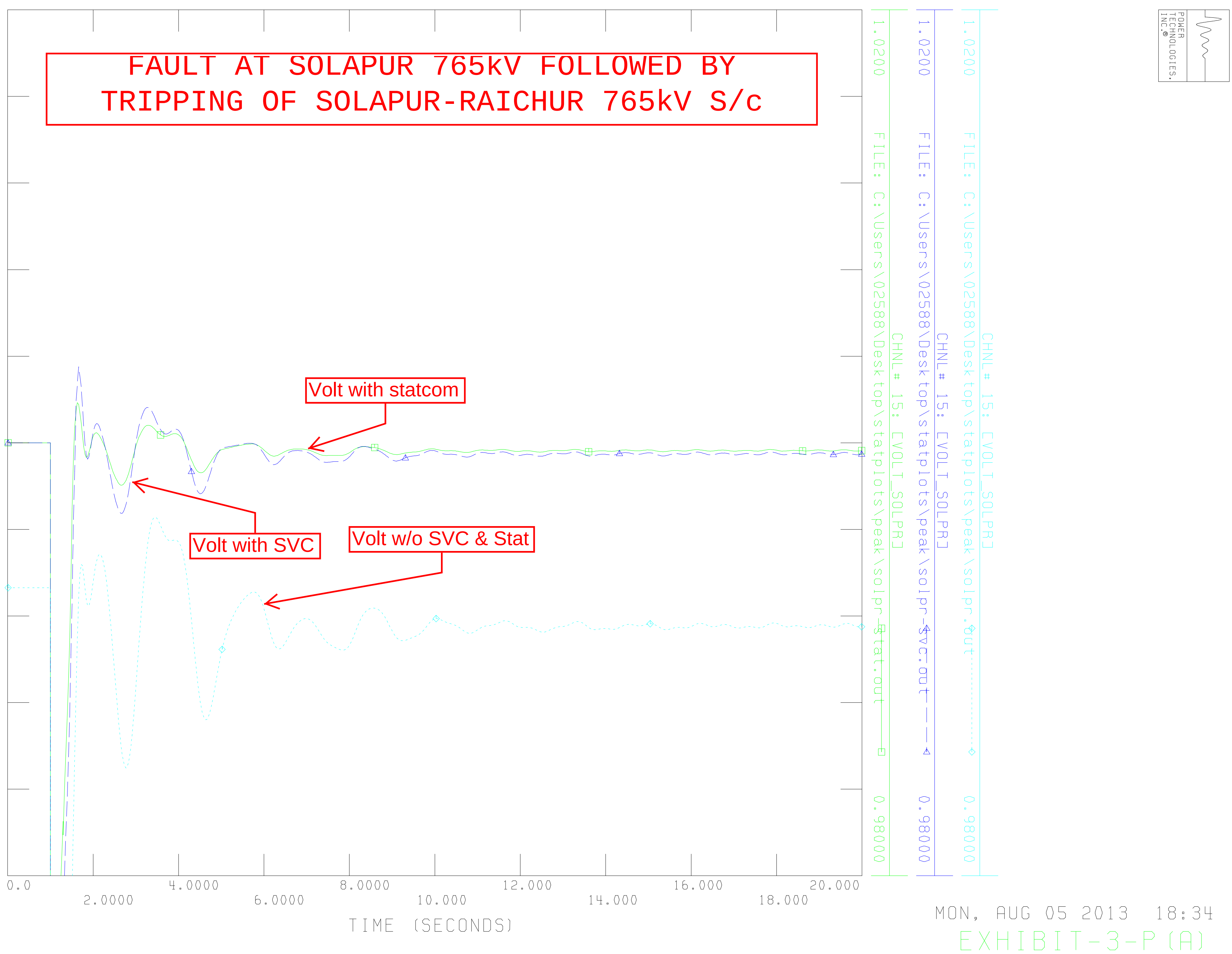


EXHIBIT-2-OP(b)

WED, AUG 07 2013 22:34

LUCK MVAR - OFFPEAK


FAULT AT SOLAPUR 765kV FOLLOWED BY
TRIPPING OF SOLAPUR-RAICHUR 765kV S/c
Volt with statcom
Volt with SVC
Volt w/o SVC & Stat
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
1.0200
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1.0200
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CHNL# 15: [VOLT_SOLPR]
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MON, AUG 05 2013 18:34
EXHIBIT-3-P(A)

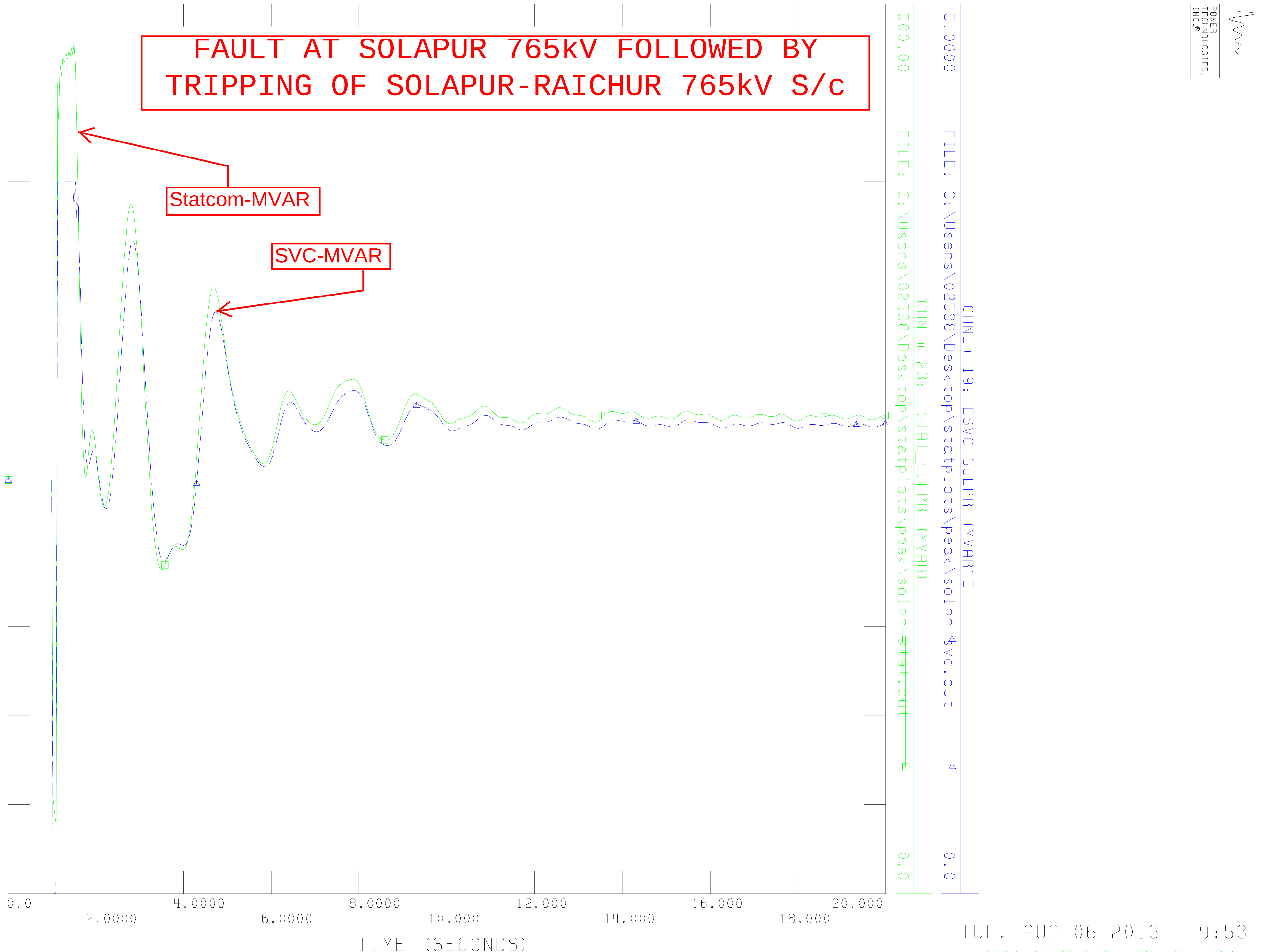

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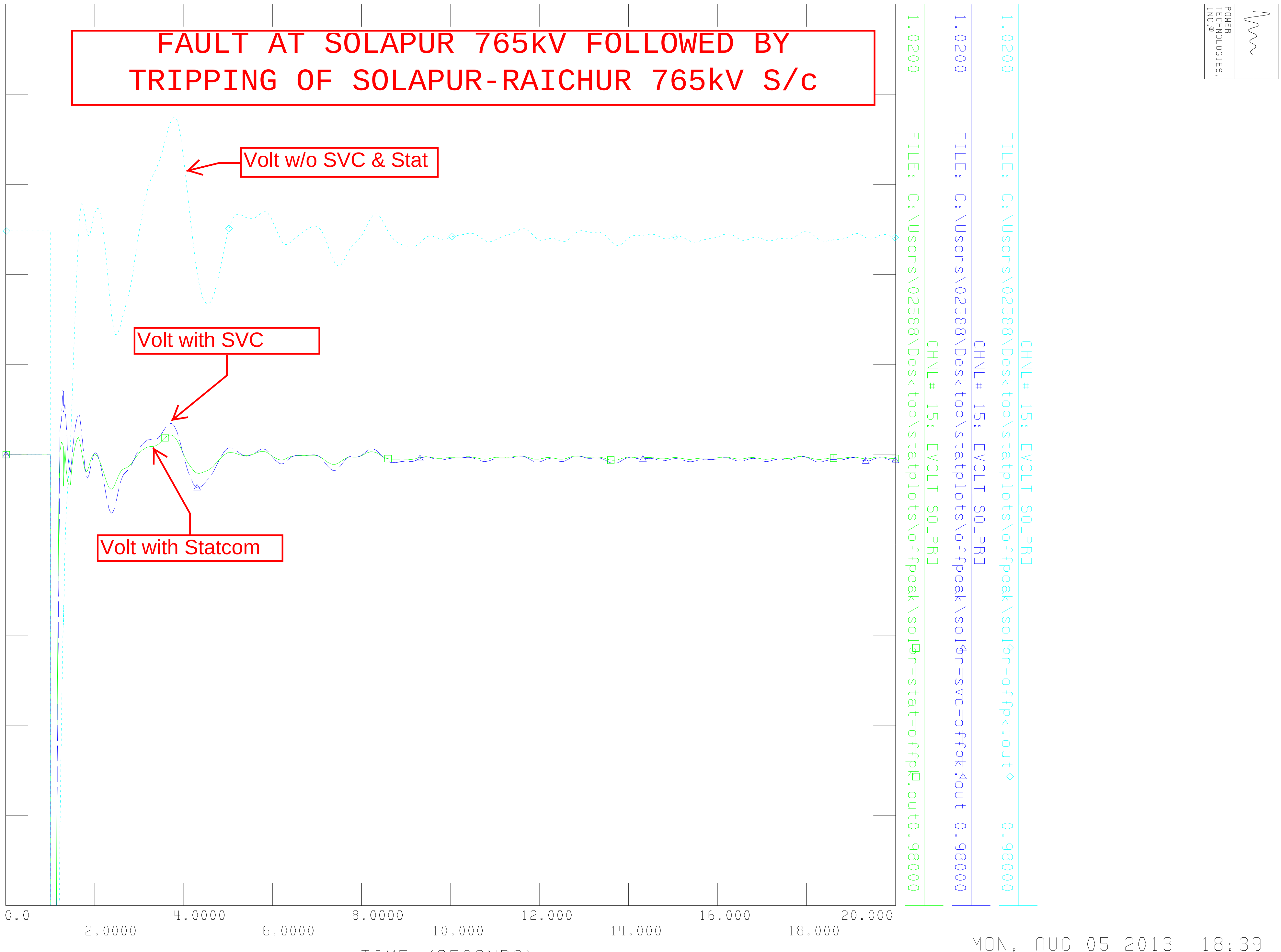
EXHIBIT-3-P(B)



MON, AUG 05 2013 18:39

EXHIBIT-3-O(A)


FAULT AT SOLAPUR 765kV FOLLOWED BY
TRIPPING OF SOLAPUR-RAICHUR 765kV S/c
Stat-MVAR
SVC-MVAR
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
500.00
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5.0000
FILE: C:\Users\02588\Desktop\statplots\offpeak\solpr-svc-offpk.out -5.000
CHNL# 19: [SVC_SOLPR (MVAR)]
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 18:57
EXHIBIT-3-O(B)

FAULT AT GWALIOR 765kV FOLLOWED BY TRIPPING OF GWALIOR-AGRA 765kV S/c
Volt w/o Stat & SVC
Volt with SVC
Volt with Statcom
1.0200
FILE: C:\Users\02588\Desktop\statplots\peak\gwal-stat.out
CHNL# 14: [VOLT_GWLR]
0.98000
1.0200
FILE: C:\Users\02588\Desktop\statplots\peak\gwal-svc.out
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2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
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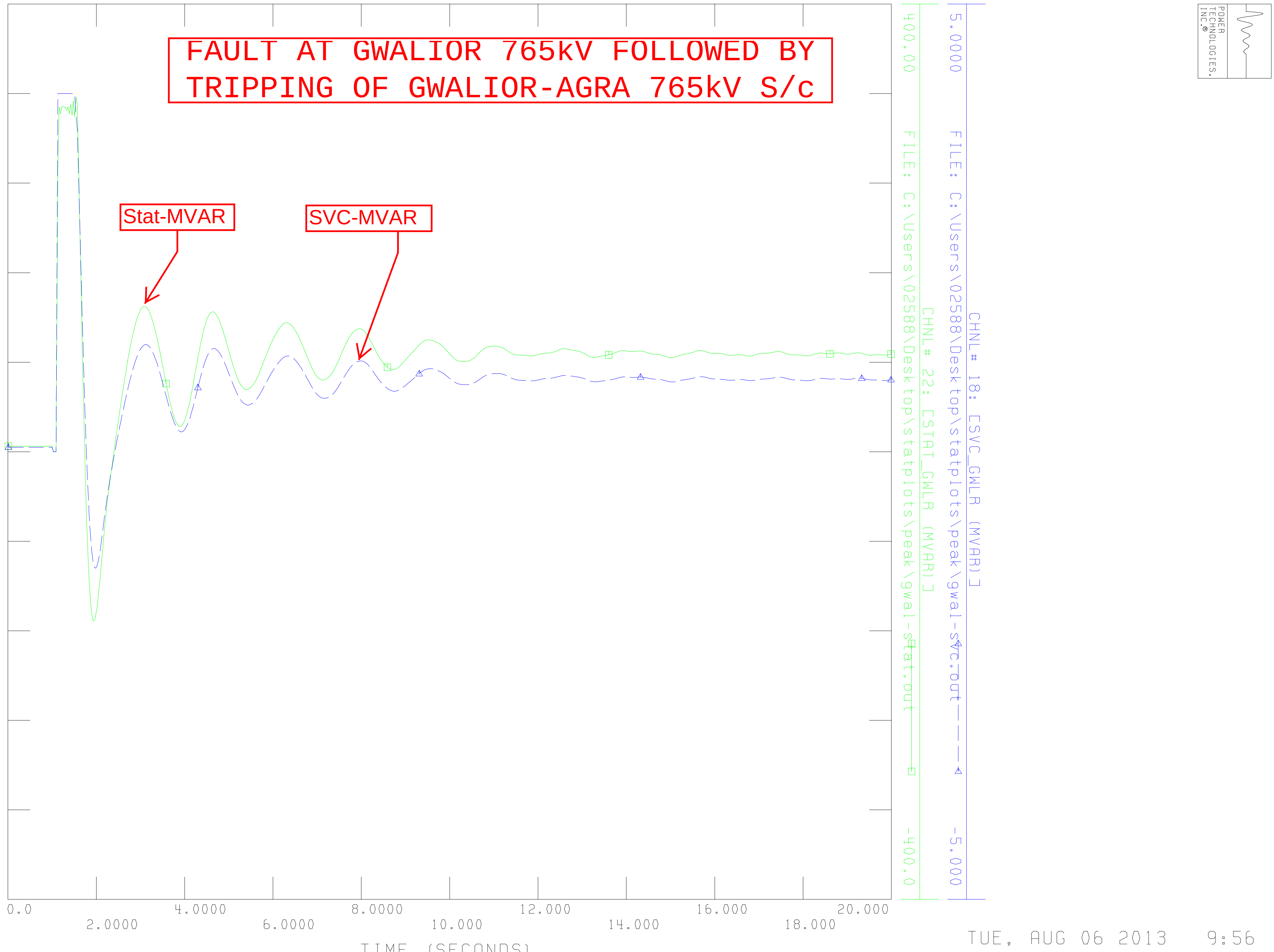
TIME (SECONDS)
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 18:35
EXHIBIT-4-P(A)



FAULT AT GWALIOR 765kV FOLLOWED BY
TRIPPING OF GWALIOR-AGRA 765kV S/c
Stat-MVAR
SVC-MVAR
400.00
-400.0
5.0000
-5.000
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FILE: C:\Users\02588\Desktop\statplots\peak\gwal-svc.out
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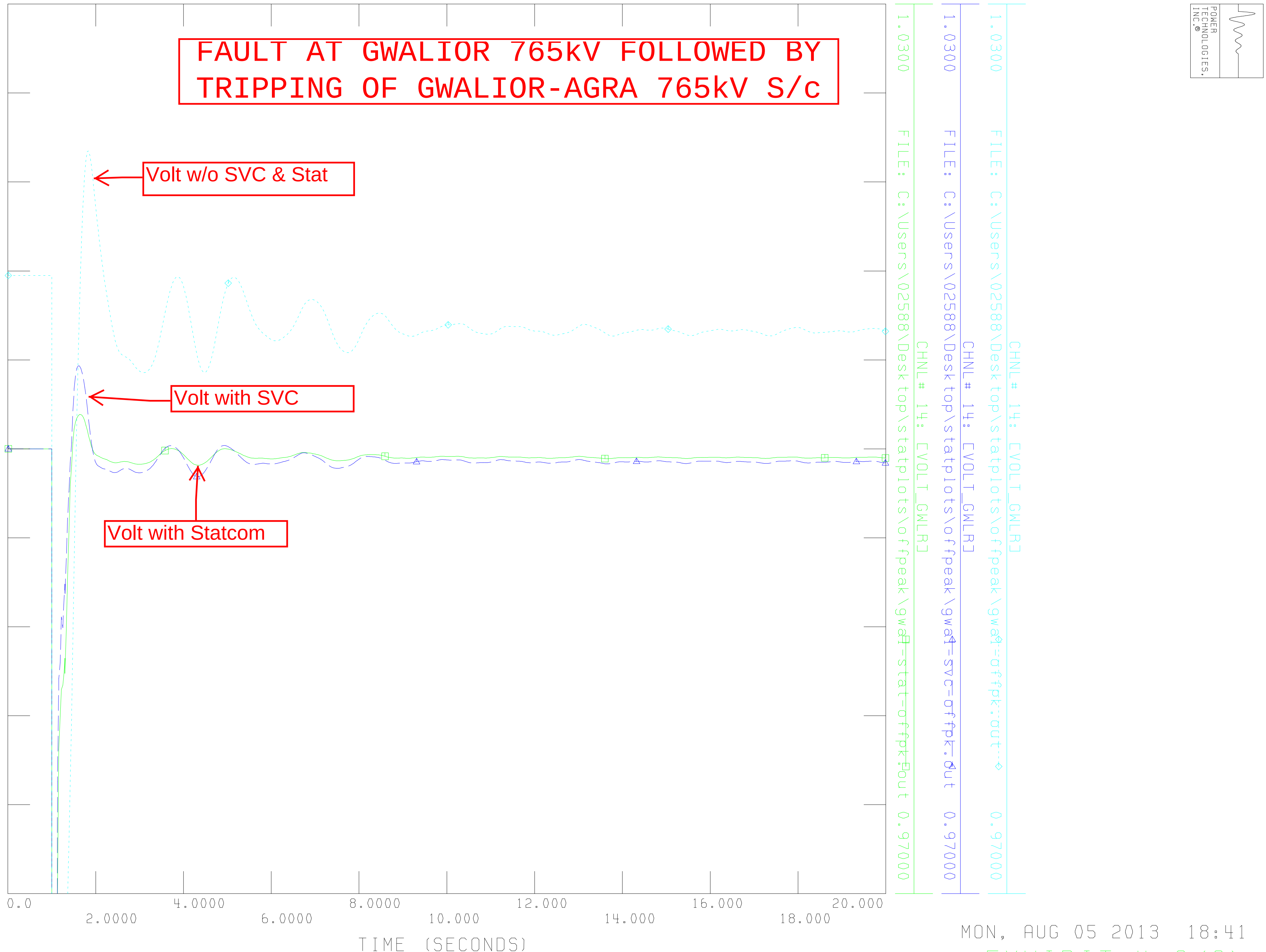
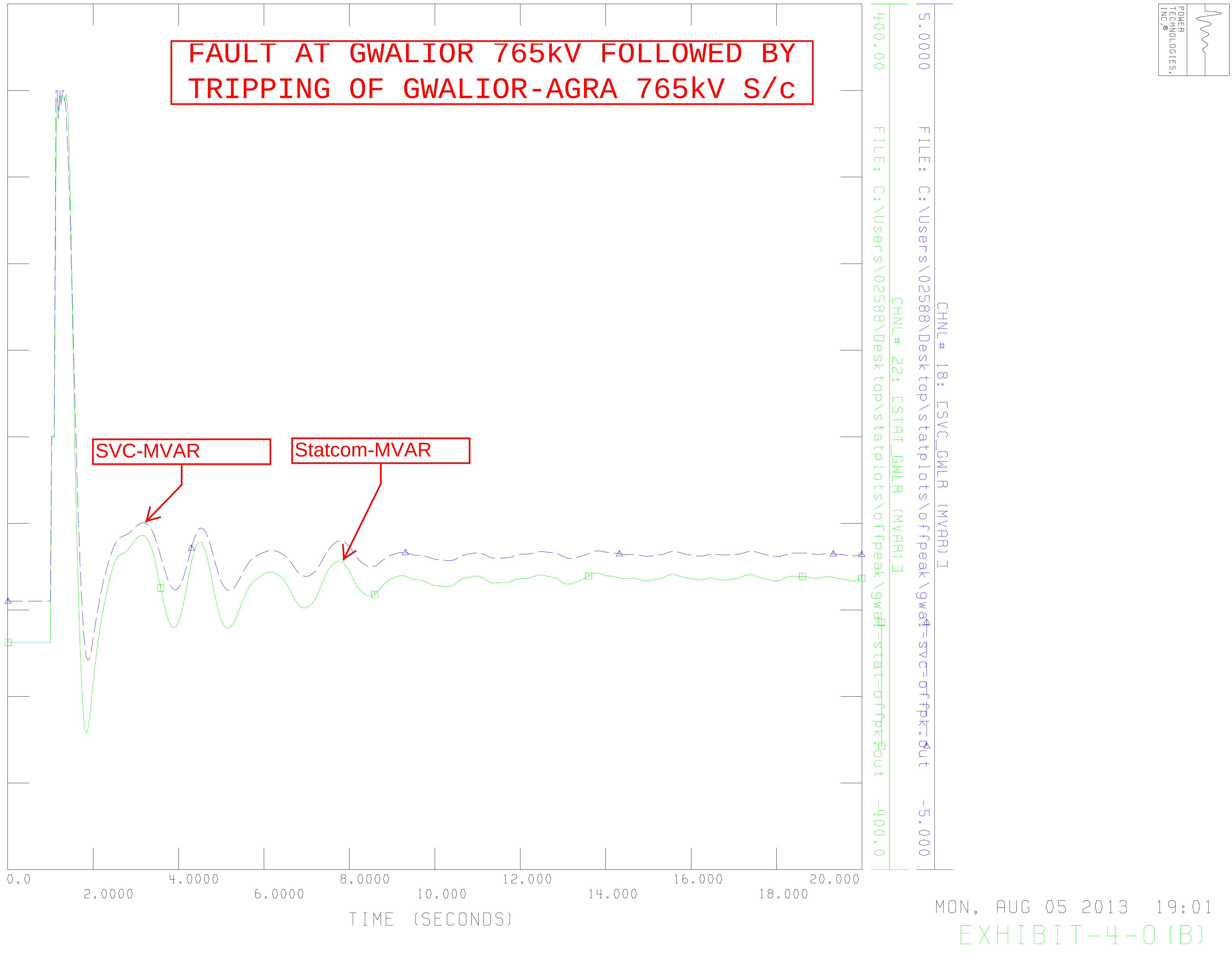
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
POWER TECHNOLOGIES, INC.®
TUE, AUG 06 2013 9:56

EXHIBIT-4-P(B)

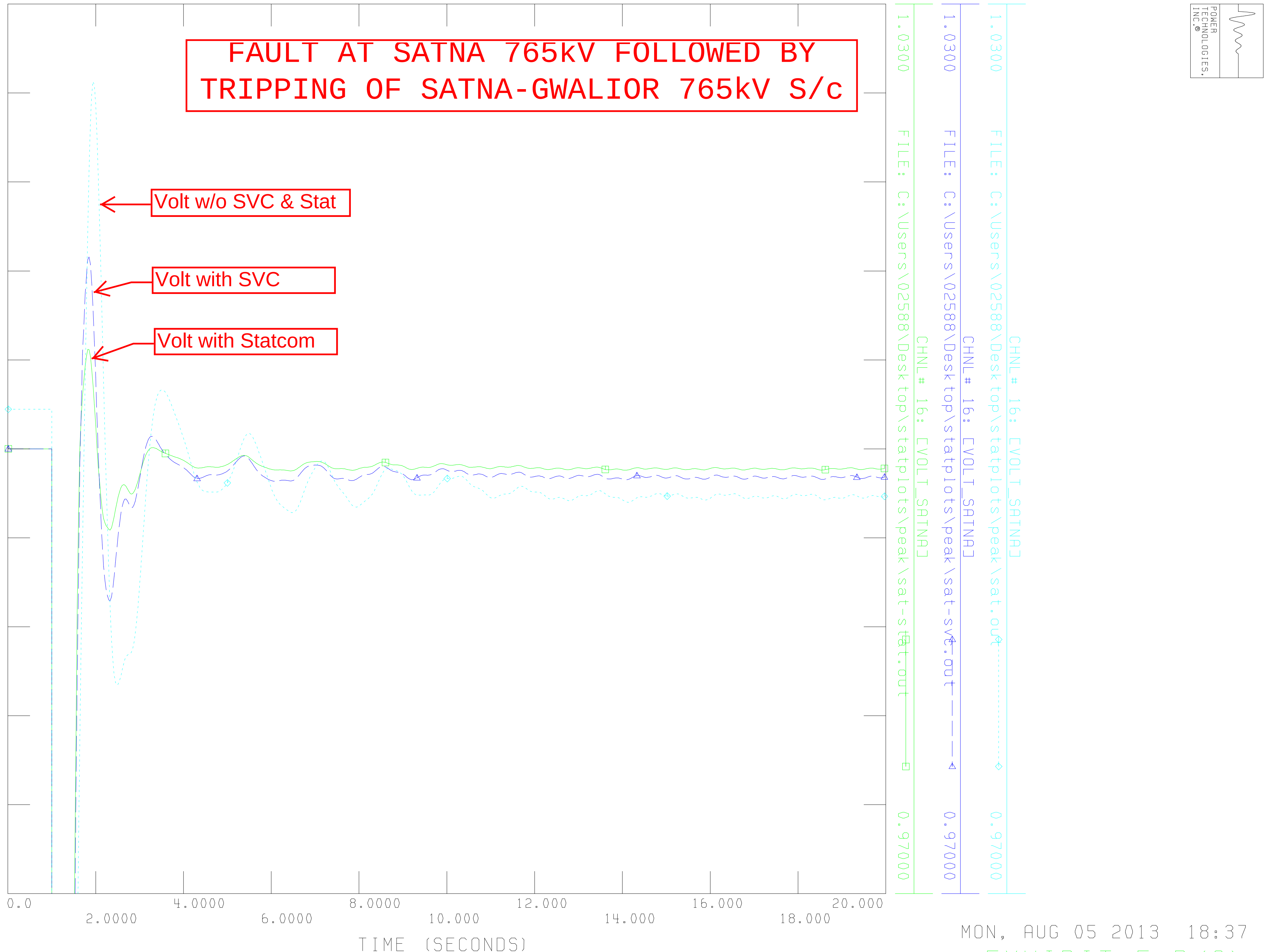


FAULT AT GWALIOR 765kV FOLLOWED BY
TRIPPING OF GWALIOR-AGRA 765kV S/c
Volt w/o SVC & Stat
Volt with SVC
Volt with Statcom
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
1.0300
FILE: C:\Users\02588\Desktop\statplots\offpeak\gwal-stat-offpk.out 0.97000
CHNL# 14: [VOLT_GWLR]
1.0300
FILE: C:\Users\02588\Desktop\statplots\offpeak\gwal-svc-offpk.out 0.97000
CHNL# 14: [VOLT_GWLR]
1.0300
FILE: C:\Users\02588\Desktop\statplots\offpeak\gwal-offpk.out 0.97000
CHNL# 14: [VOLT_GWLR]
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 18:41

EXHIBIT-4-O(A)



FAULT AT GWALIOR 765kV FOLLOWED BY
TRIPPING OF GWALIOR-AGRA 765kV S/c
SVC-MVAR
Statcom-MVAR
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
400.00
FILE: C:\Users\02588\Desktop\statplots\offpeak\gwal-stat-offpk.out
-400.0
CHNL# 22: [STAT_GWLR (MVAR)]
5.0000
FILE: C:\Users\02588\Desktop\statplots\offpeak\gwal-svc-offpk.out
-5.000
CHNL# 18: [SVC_GWLR (MVAR)]
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 19:01
EXHIBIT-4-O(B)



MON, AUG 05 2013 18:37

EXHIBIT-5-P(A)

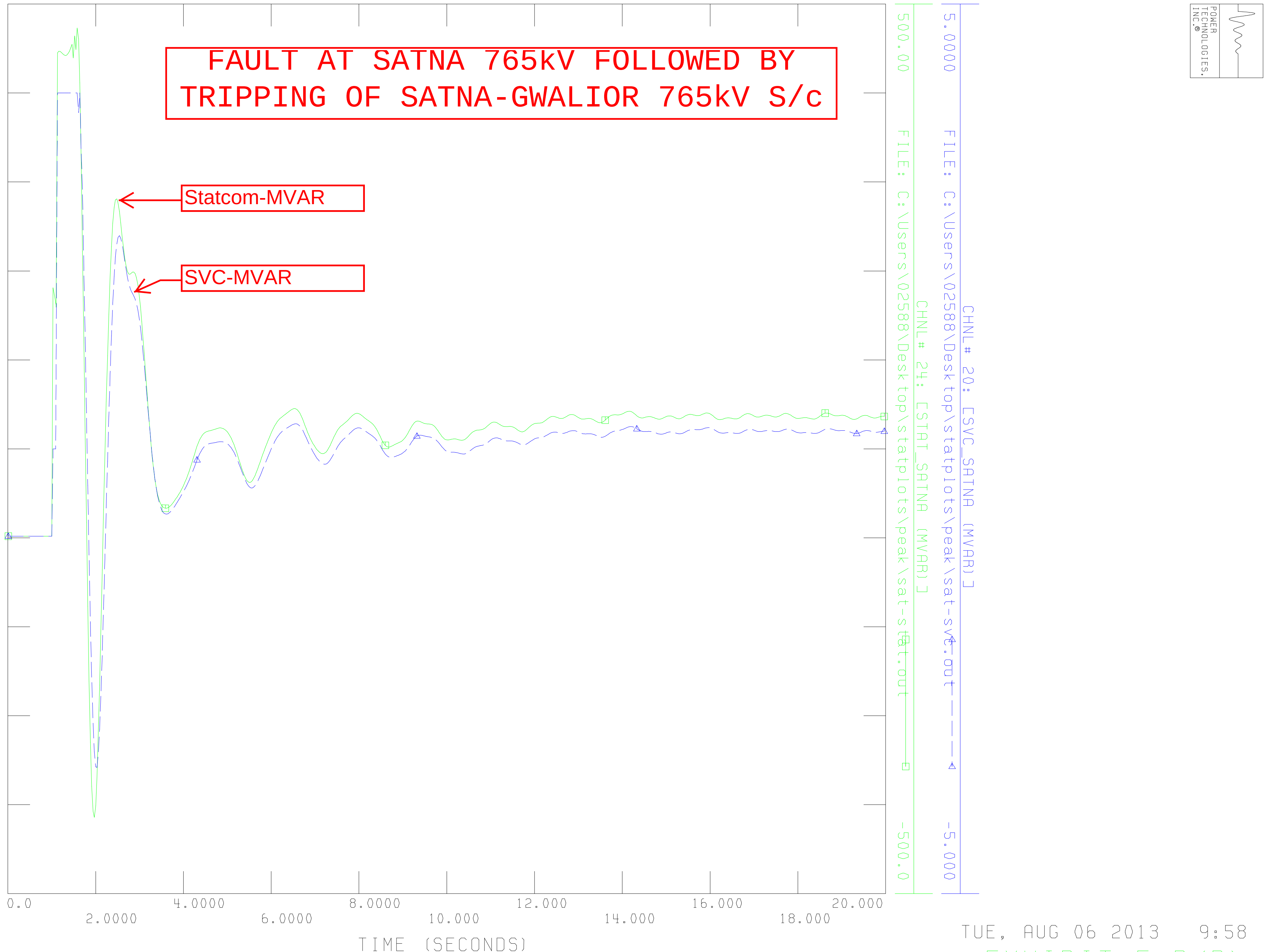
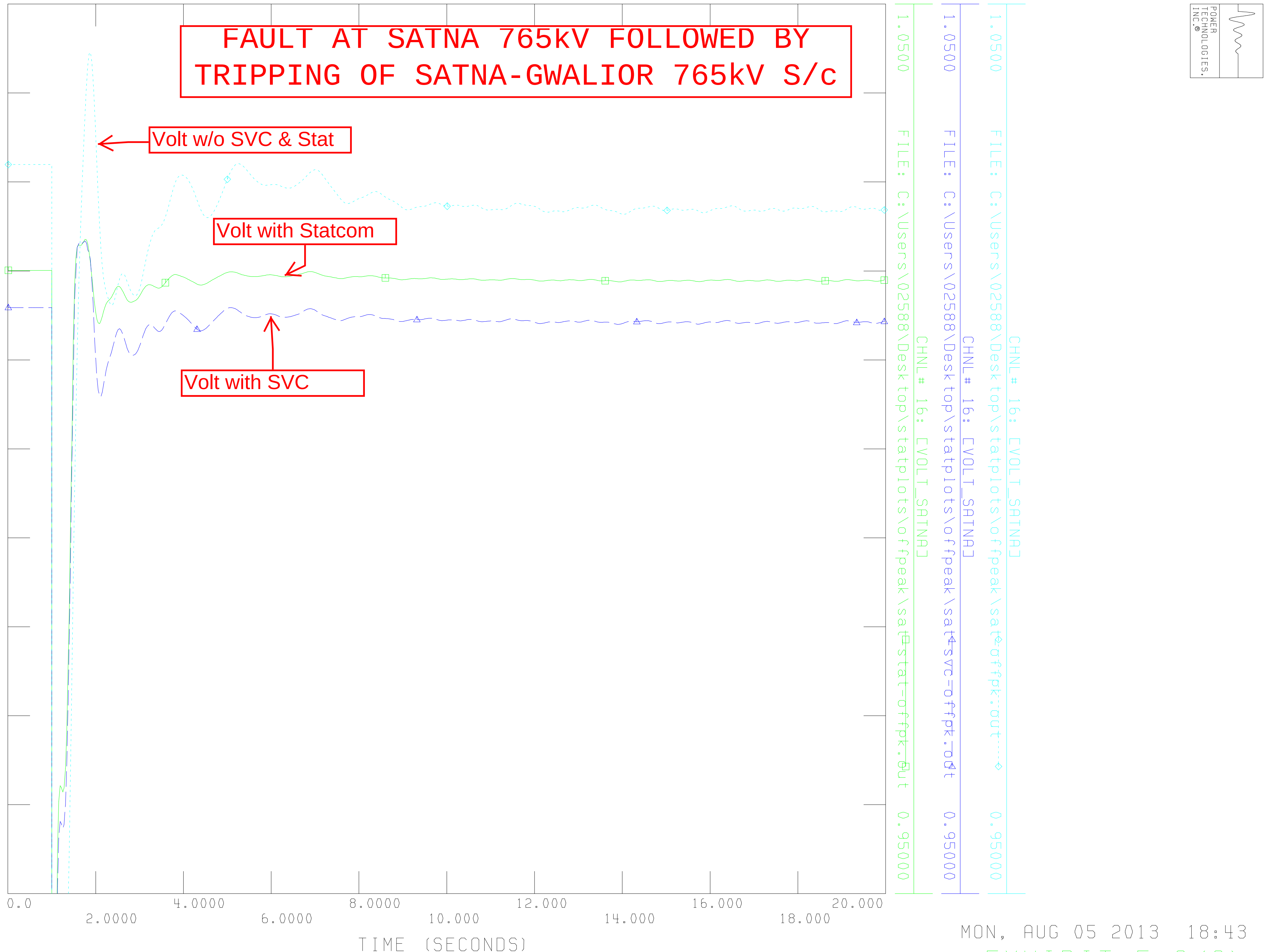
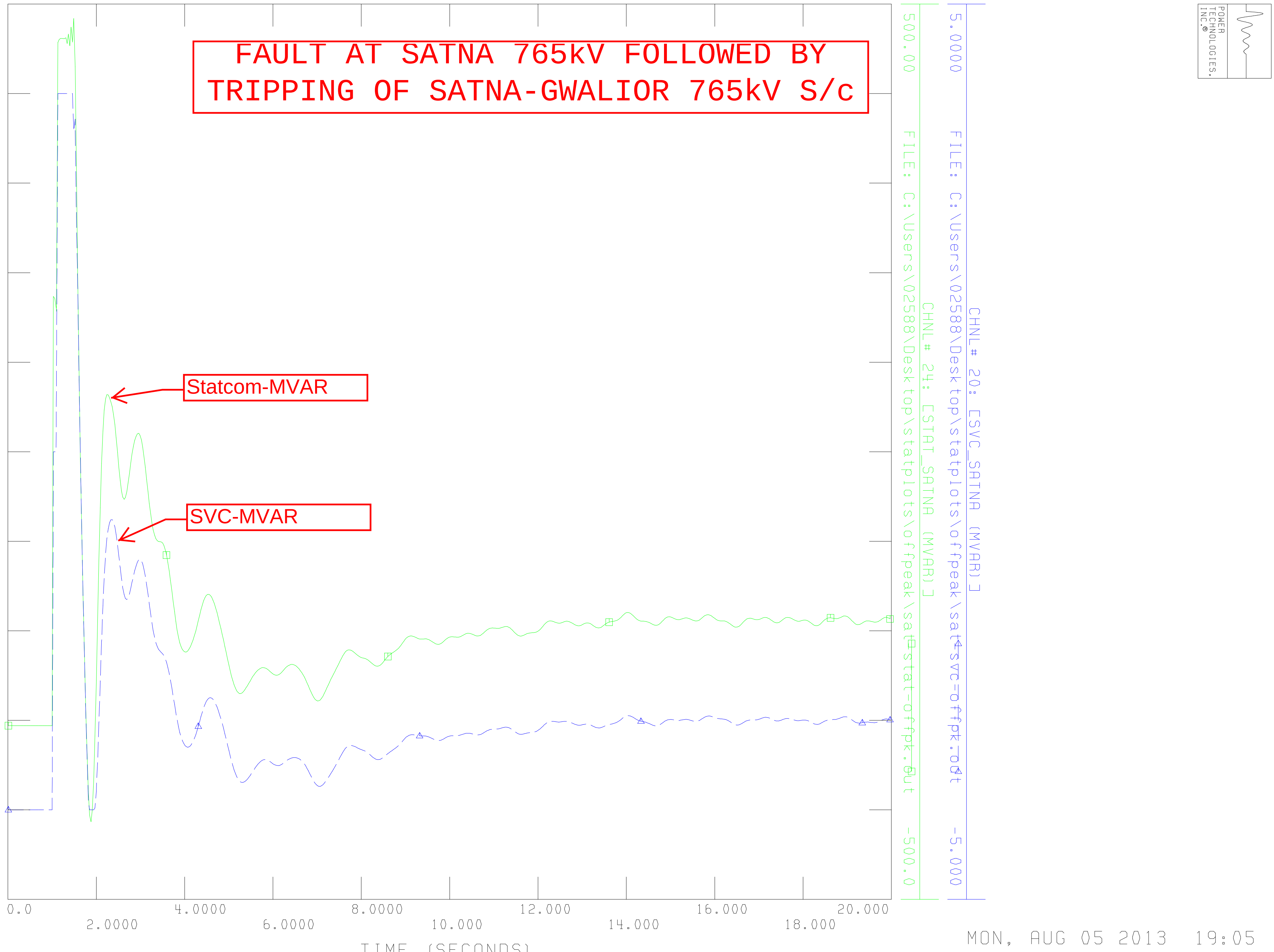

FAULT AT SATNA 765kV FOLLOWED BY
TRIPPING OF SATNA-GWALIOR 765kV S/c
Statcom-MVAR
SVC-MVAR
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
500.00
-500.0
FILE: C:\Users\02588\Desktop\statplots\peak\sat-stat.out
CHNL# 24: [STAT_SATNA (MVAR)]
5.0000
-5.000
FILE: C:\Users\02588\Desktop\statplots\peak\sat-svc.out
CHNL# 20: [SVC_SATNA (MVAR)]
POWER TECHNOLOGIES, INC.®
TUE, AUG 06 2013 9:58

EXHIBIT-5-P(B)



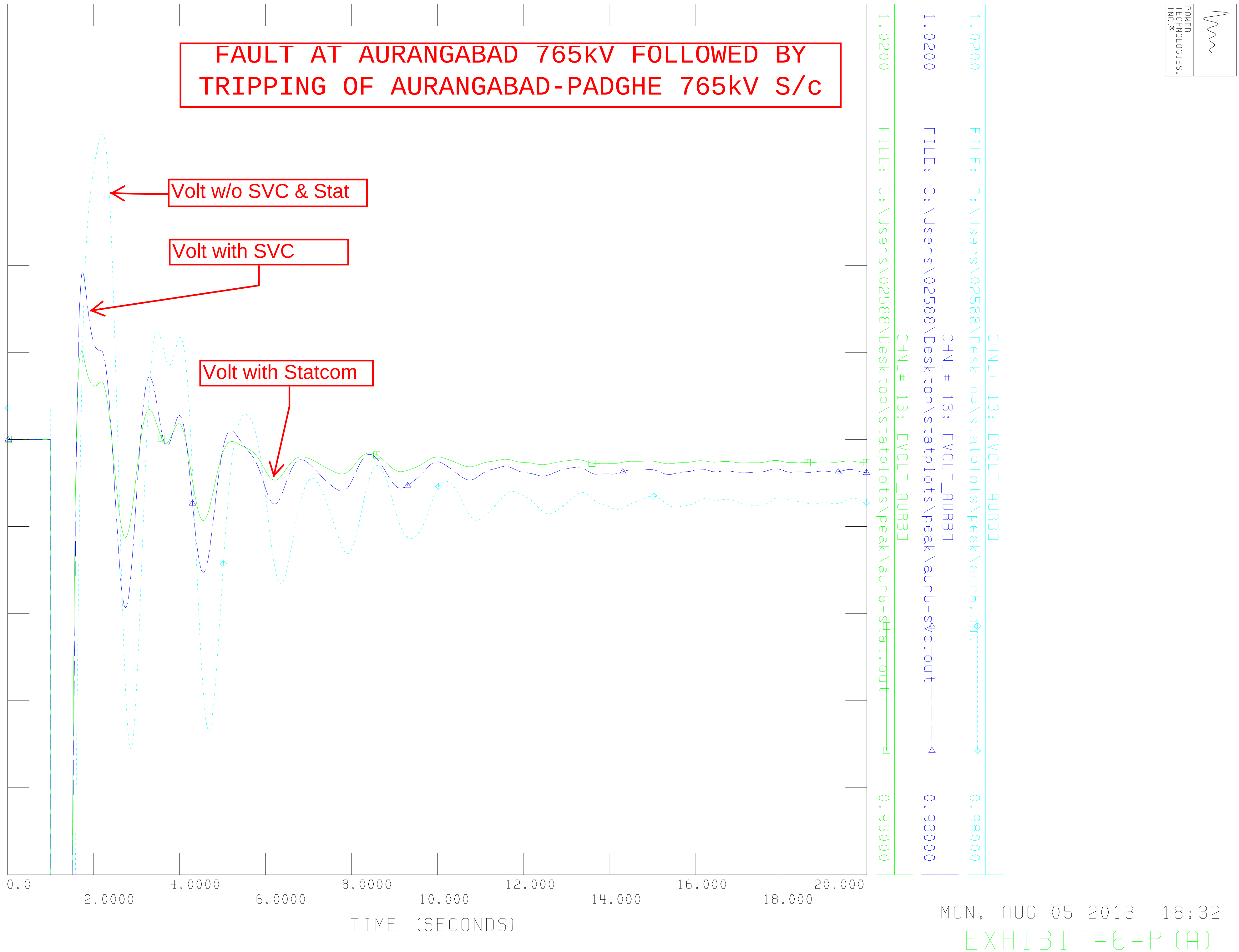
MON, AUG 05 2013 18:43

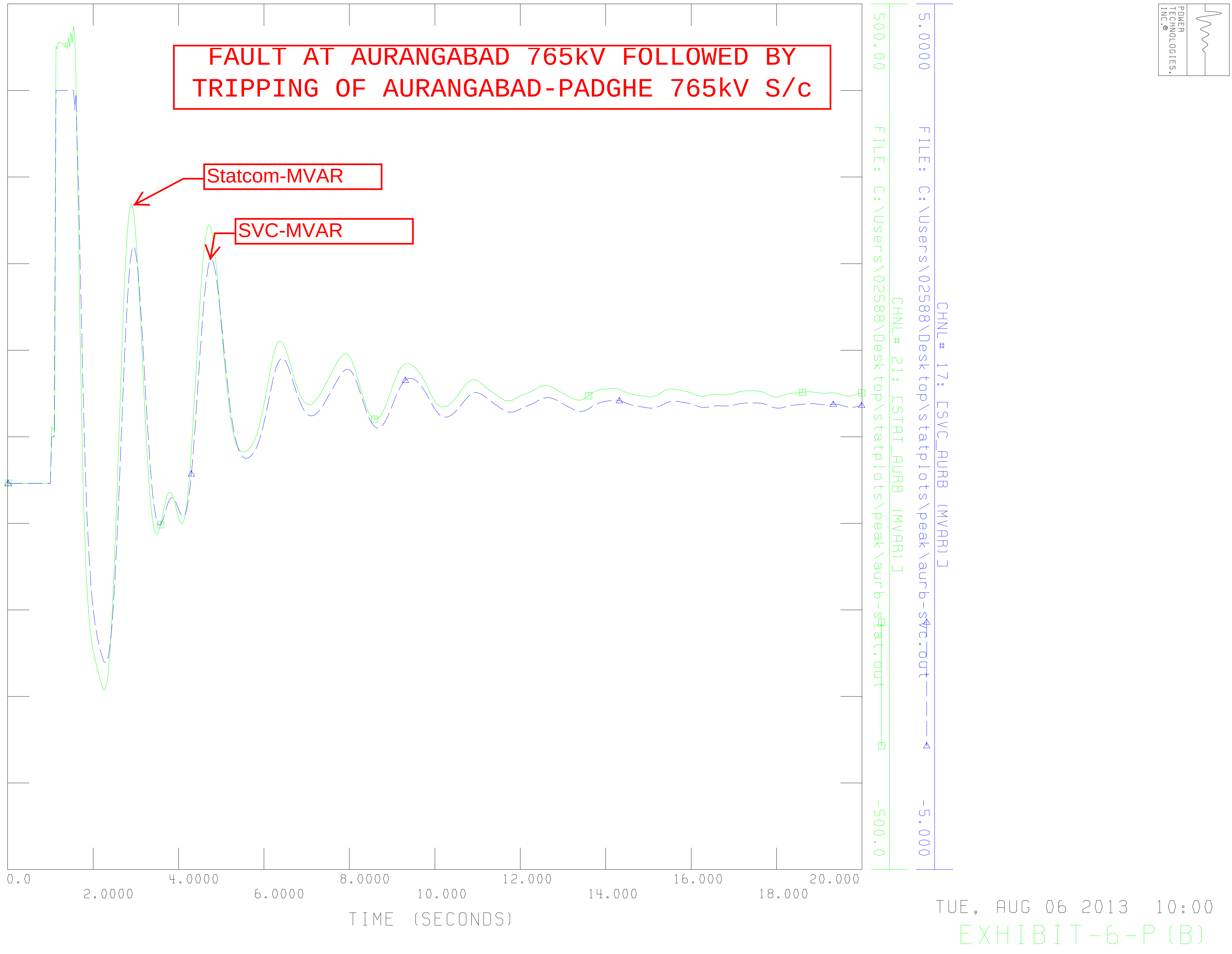
EXHIBIT-5-O(A)



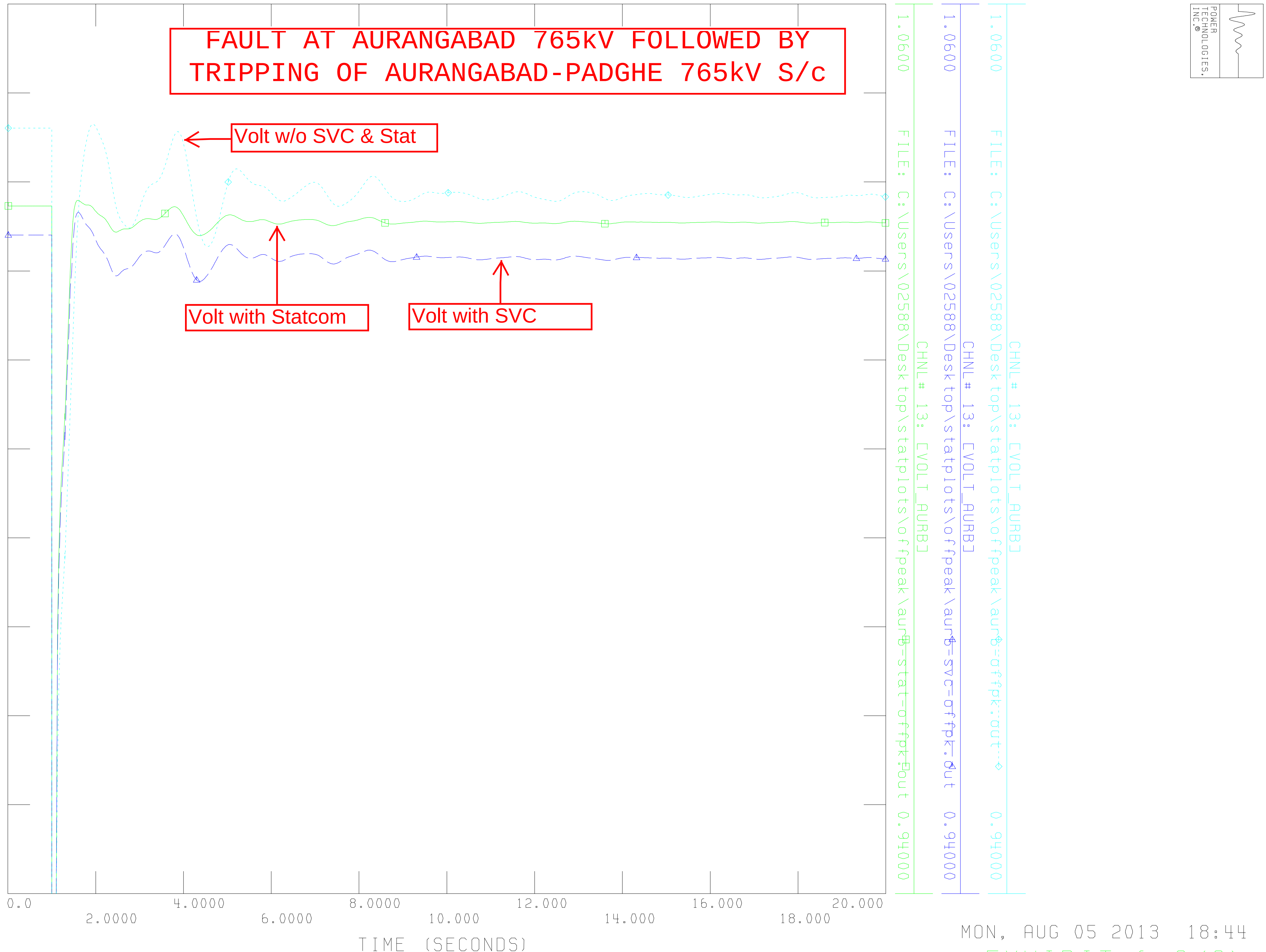
FAULT AT SATNA 765kV FOLLOWED BY
TRIPPING OF SATNA-GWALIOR 765kV S/c
Statcom-MVAR
SVC-MVAR
500.00
FILE: C:\Users\02588\Desktop\statplots\offpeak\sat-stat-offpk.out
CHNL# 24: [STAT_SATNA (MVAR)]
-500.0
5.0000
FILE: C:\Users\02588\Desktop\statplots\offpeak\sat-svc-offpk.out
CHNL# 20: [SVC_SATNA (MVAR)]
-5.000
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 19:05

EXHIBIT-5-0(B)


FAULT AT AURANGABAD 765kV FOLLOWED BY
TRIPPING OF AURANGABAD-PADGHE 765kV S/c
Volt w/o SVC & Stat
Volt with SVC
Volt with Statcom
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
1.0200
FILE: C:\Users\02588\Desktop\statplots\peak\aurb-stat.out
CHNL# 13: [VOLT_AURB]
0.98000
1.0200
FILE: C:\Users\02588\Desktop\statplots\peak\aurb-svc.out
CHNL# 13: [VOLT_AURB]
0.98000
1.0200
FILE: C:\Users\02588\Desktop\statplots\peak\aurb.out
CHNL# 13: [VOLT_AURB]
0.98000
POWER TECHNOLOGIES, INC.®
MON, AUG 05 2013 18:32
EXHIBIT-6-P(A)

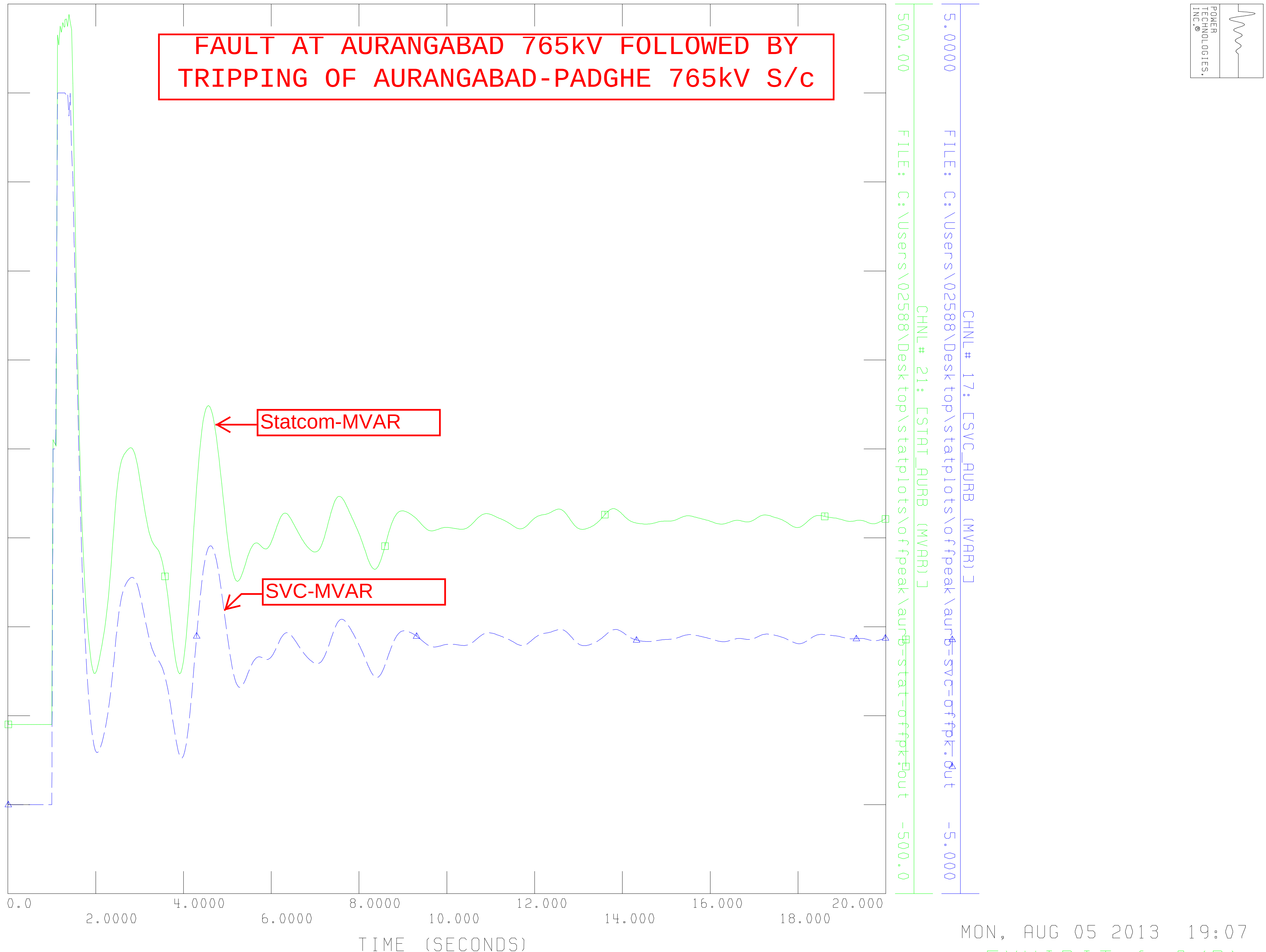


FAULT AT AURANGABAD 765kV FOLLOWED BY
TRIPPING OF AURANGABAD-PADGHE 765kV S/c
Statcom-MVAR
SVC-MVAR
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
500.00
-500.0
FILE: C:\Users\02588\Desktop\statplots\peak\aurb-stat.out
CHNL# 21: [STAT_AURB (MVAR)]
5.0000
-5.000
FILE: C:\Users\02588\Desktop\statplots\peak\aurb-svc.out
CHNL# 17: [SVC_AURB (MVAR)]
POWER TECHNOLOGIES, INC.®
TUE, AUG 06 2013 10:00
EXHIBIT-6-P(B)



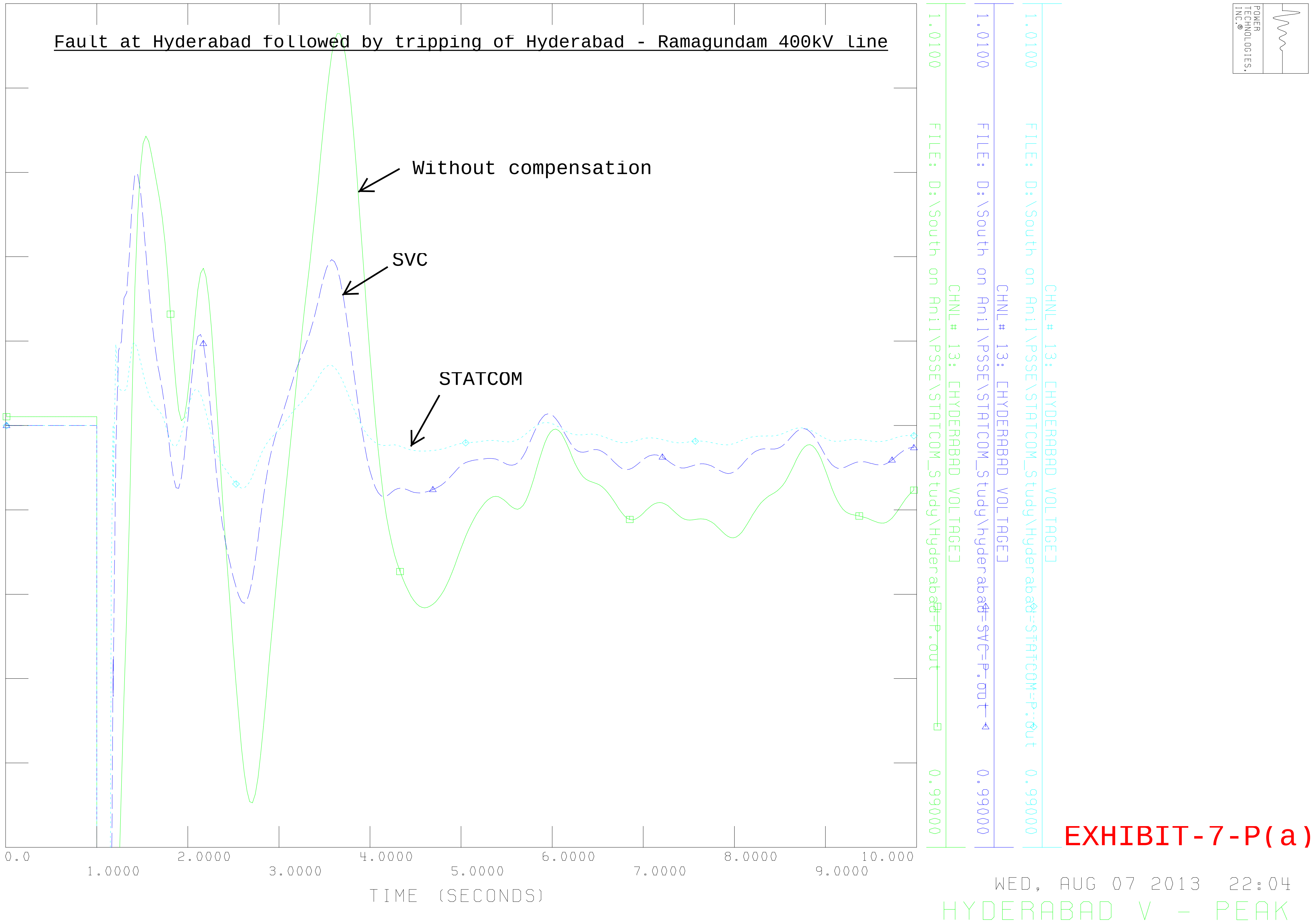
MON, AUG 05 2013 18:44

EXHIBIT-6-O(A)



MON, AUG 05 2013 19:07

EXHIBIT-6-O(B)



Fault at Hyderabad followed by tripping of Hyderabad - Ramagundam 400kV line
Without compensation
SVC
STATCOM
0.0
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
9.0000
10.000
TIME (SECONDS)
FILE: D:\South on Anil\PSSE\STATCOM_Study\Hyderabad-P.out
CHNL# 13: [HYDERABAD VOLTAGE]
1.0100
0.99000
FILE: D:\South on Anil\PSSE\STATCOM_Study\hyderabad-SVC-P.out
CHNL# 13: [HYDERABAD VOLTAGE]
1.0100
0.99000
FILE: D:\South on Anil\PSSE\STATCOM_Study\Hyderabad-STATCOM-P.out
CHNL# 13: [HYDERABAD VOLTAGE]
1.0100
0.99000
POWER TECHNOLOGIES, INC.®
WED, AUG 07 2013 22:04
HYDERABAD V - PEAK

EXHIBIT-7-P(a)

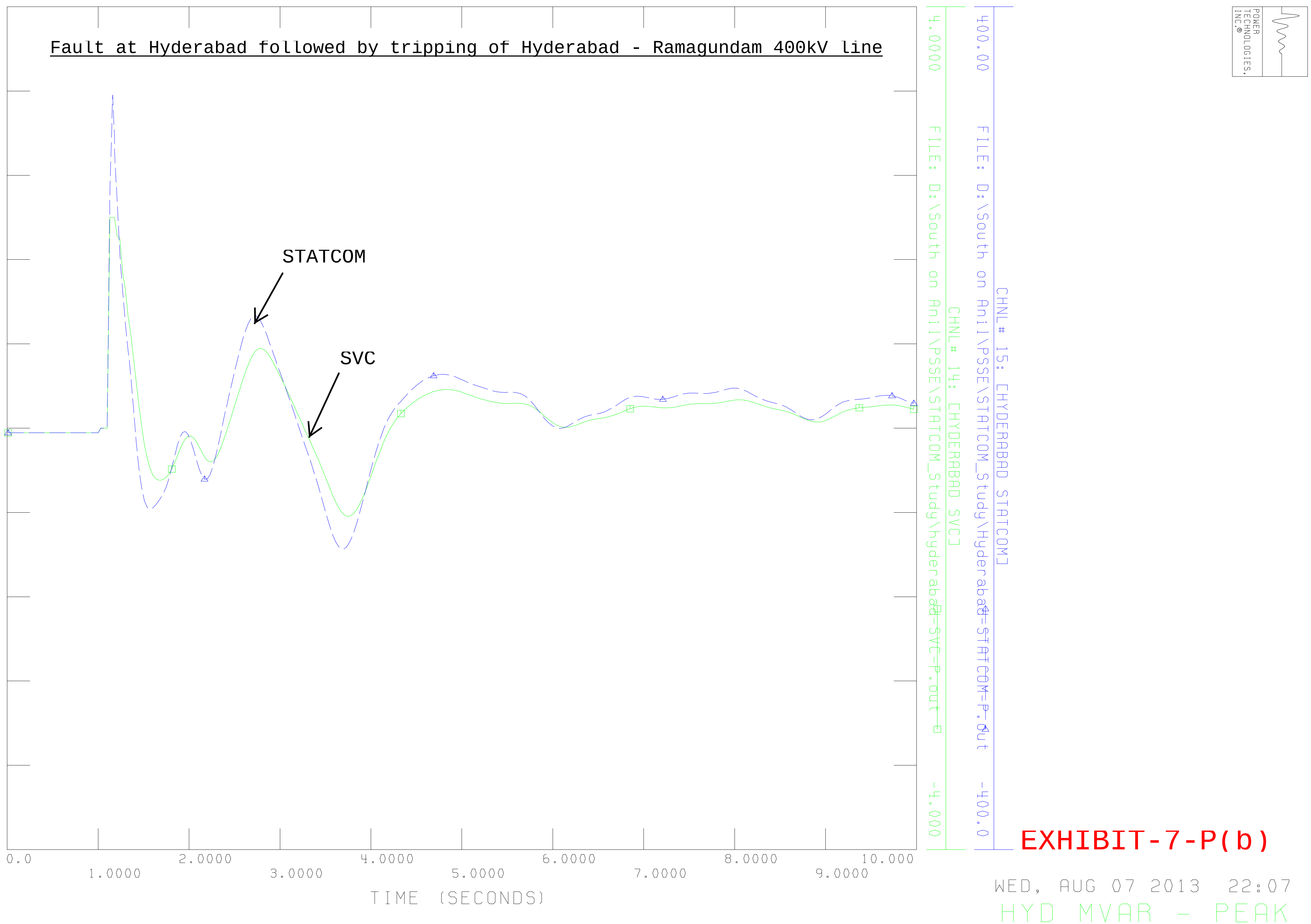


EXHIBIT-7-P(b)

WED, AUG 07 2013 22:07

HYD MVAR - PEAK

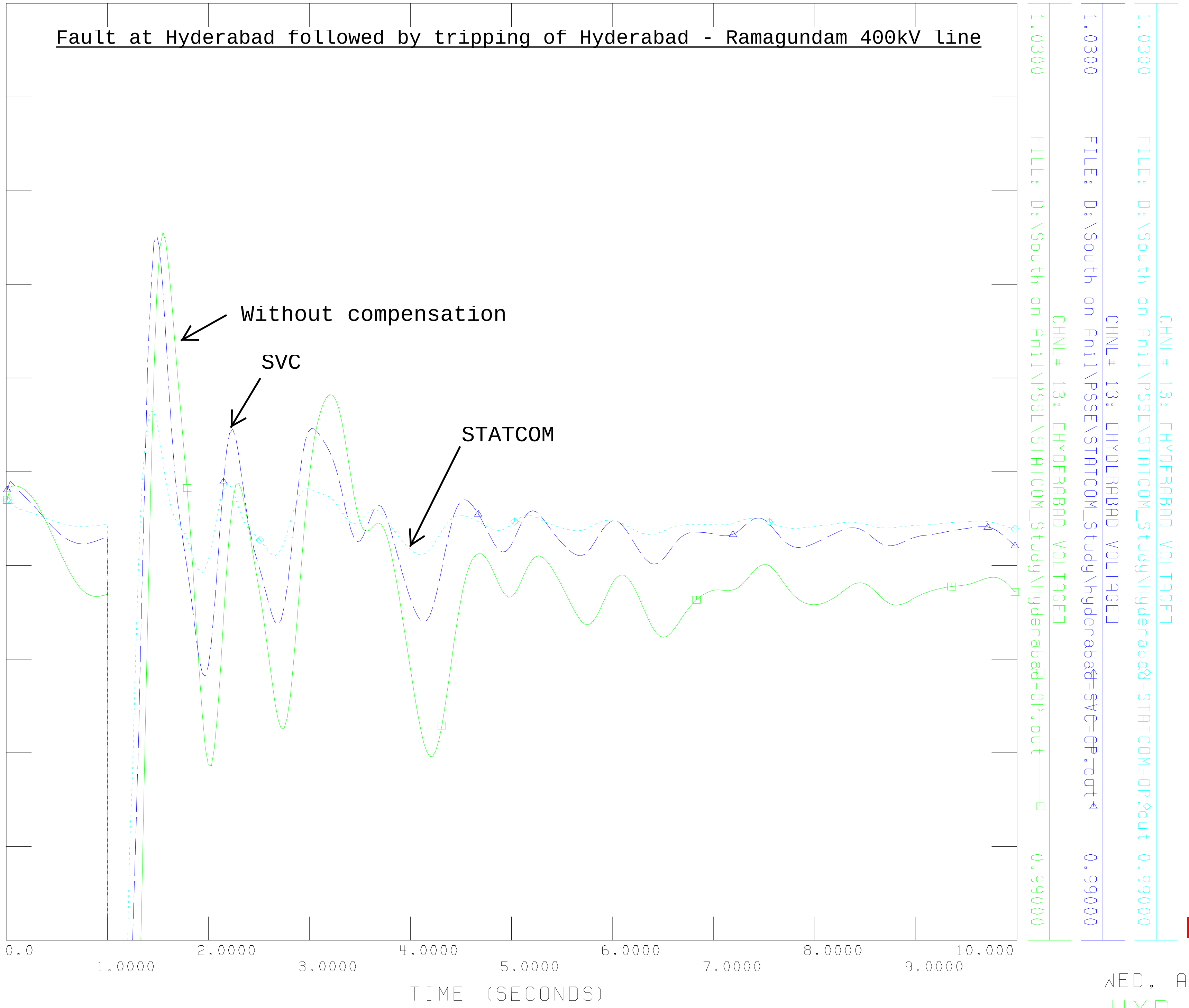


EXHIBIT-7-OP(a)

WED, AUG 07 2013 22:09

HYD V - OFFPEAK

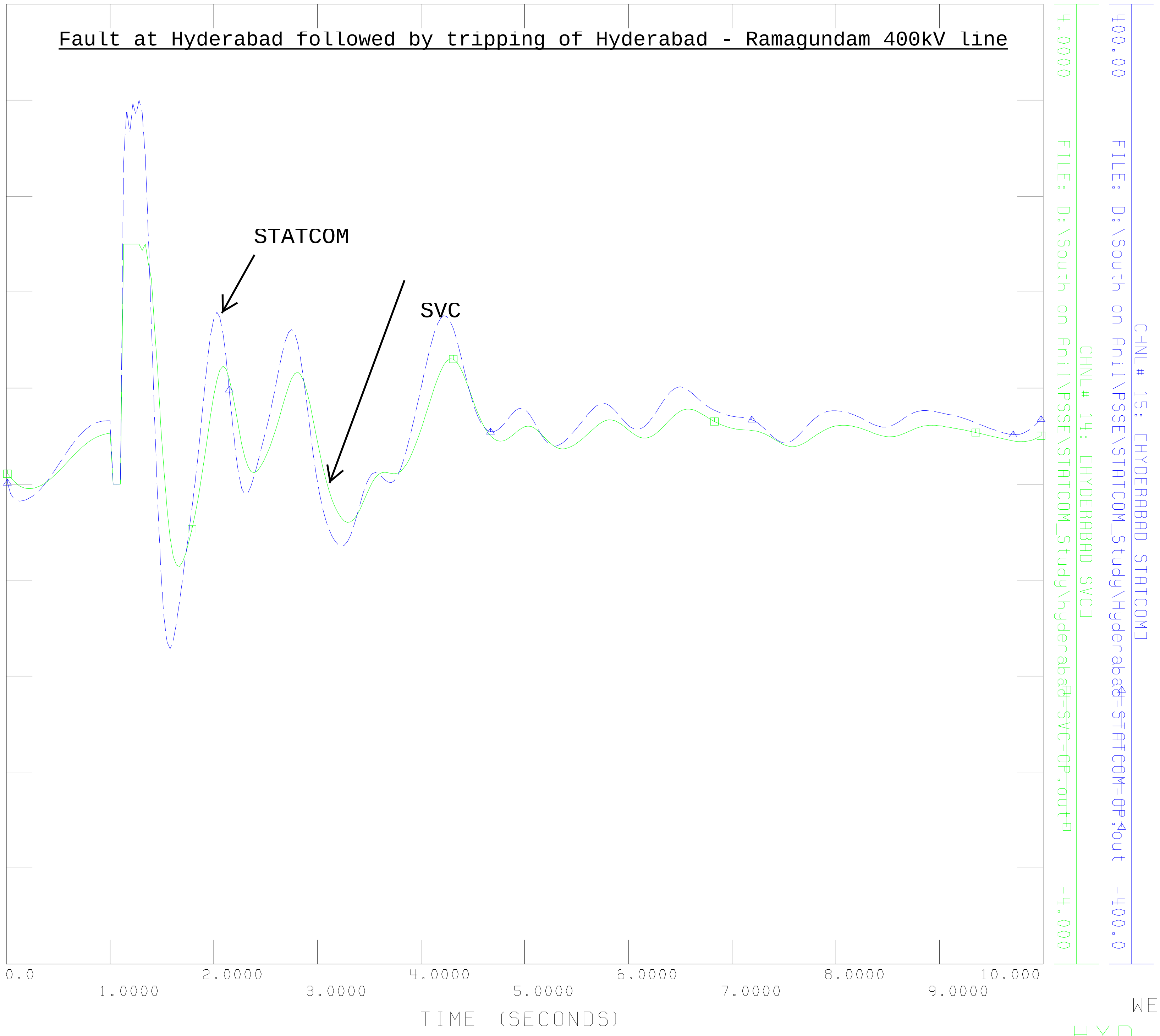


EXHIBIT-7-OP(b)

WED, AUG 07 2013 22:12

HYD MVAR - OFFPEAK

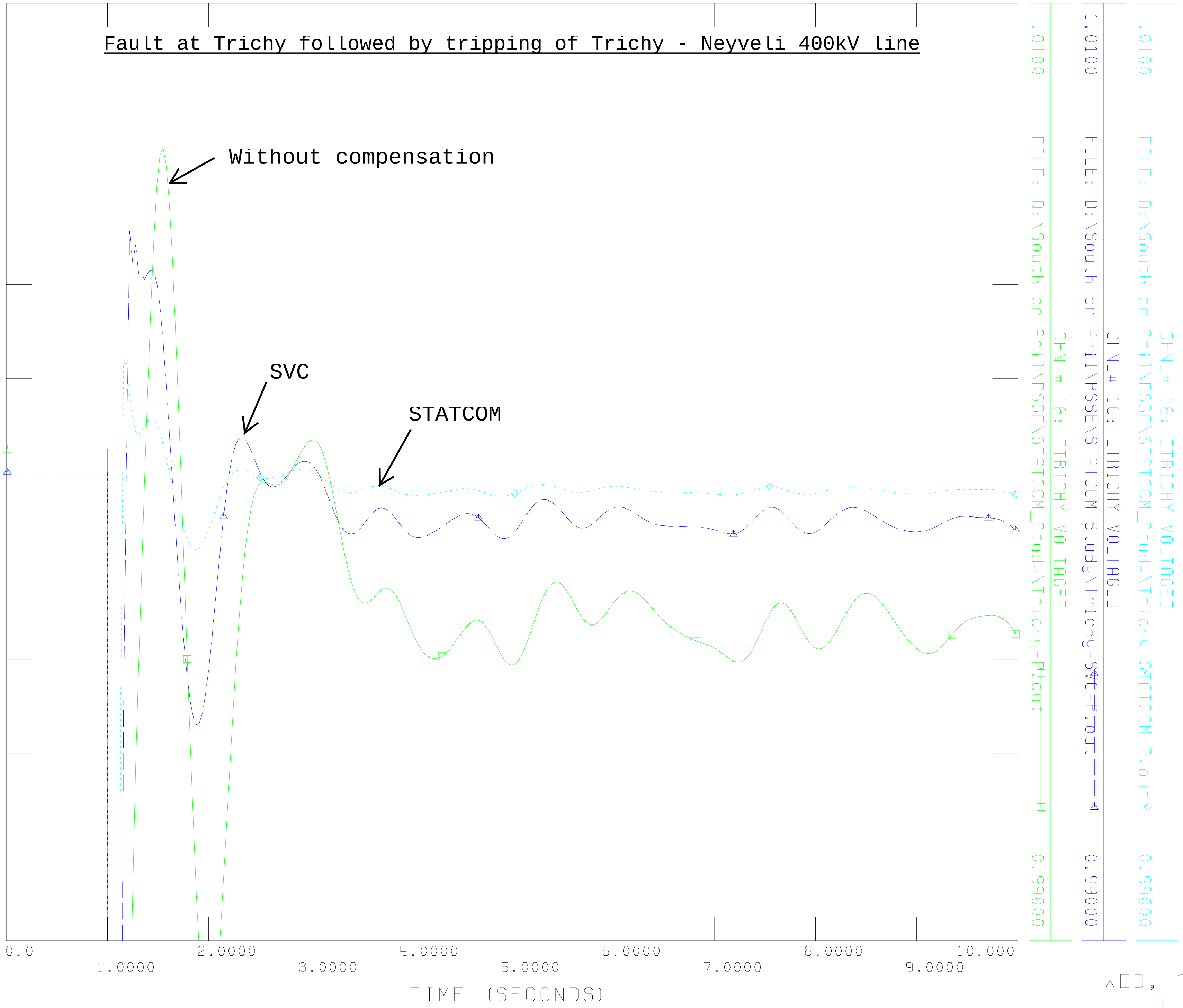
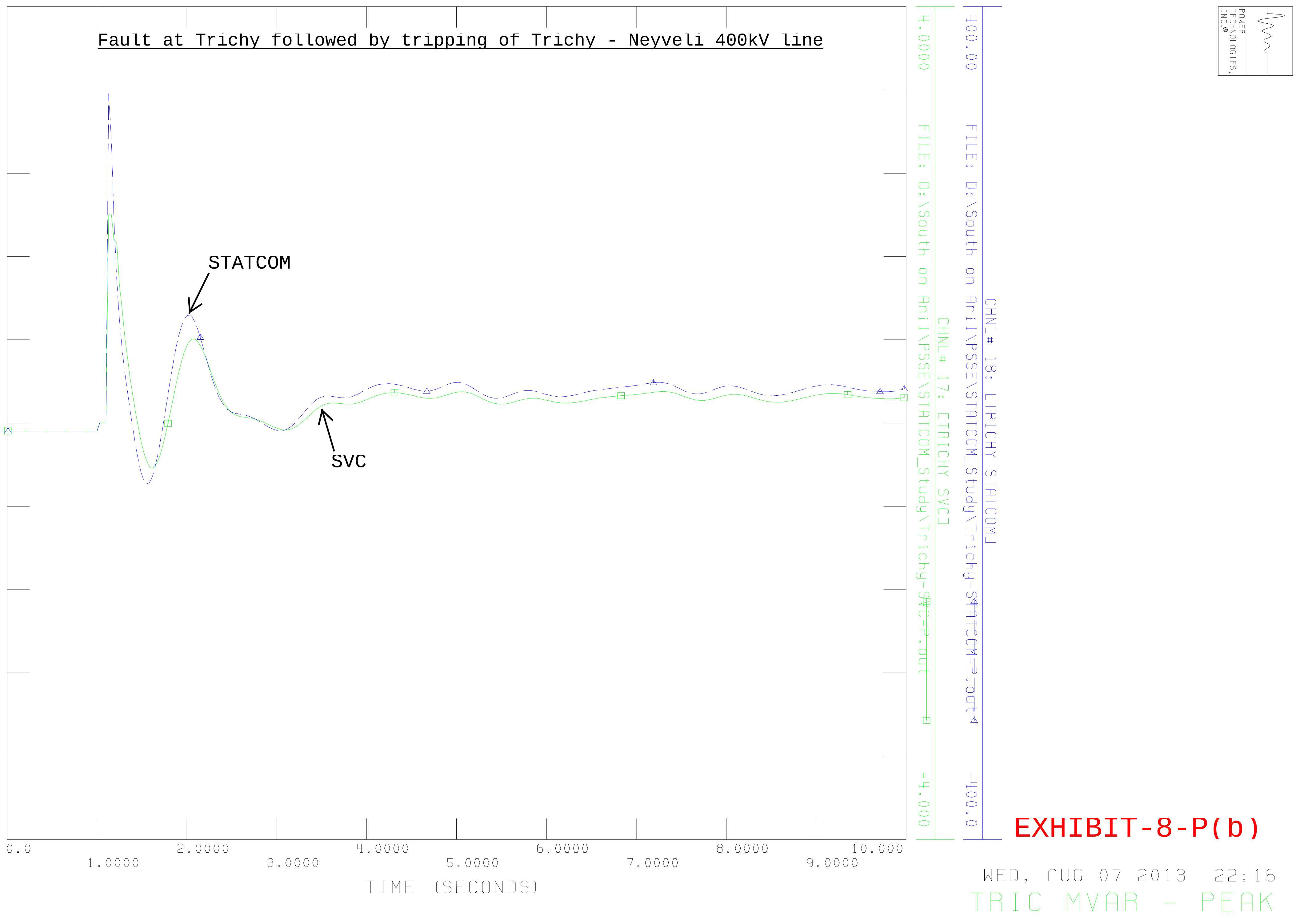


EXHIBIT-8-P(a)

WED, AUG 07 2013 22:14

TRIC V - PEAK



Fault at Trichy followed by tripping of Trichy - Neyveli 400kV line
STATCOM
SVC
0.0
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
9.0000
10.000
TIME (SECONDS)
4.0000
-4.000
FILE: D:\South on Ani\PSSE\STATCOM_Study\Trichy-SVC-P.out
CHNL# 17: [TRICHY SVC]
400.00
-400.0
FILE: D:\South on Ani\PSSE\STATCOM_Study\Trichy-STATCOM-P.out
CHNL# 18: [TRICHY STATCOM]
POWER TECHNOLOGIES, INC.®
WED, AUG 07 2013 22:16
TRIC MVAR - PEAK

EXHIBIT-8-P(b)

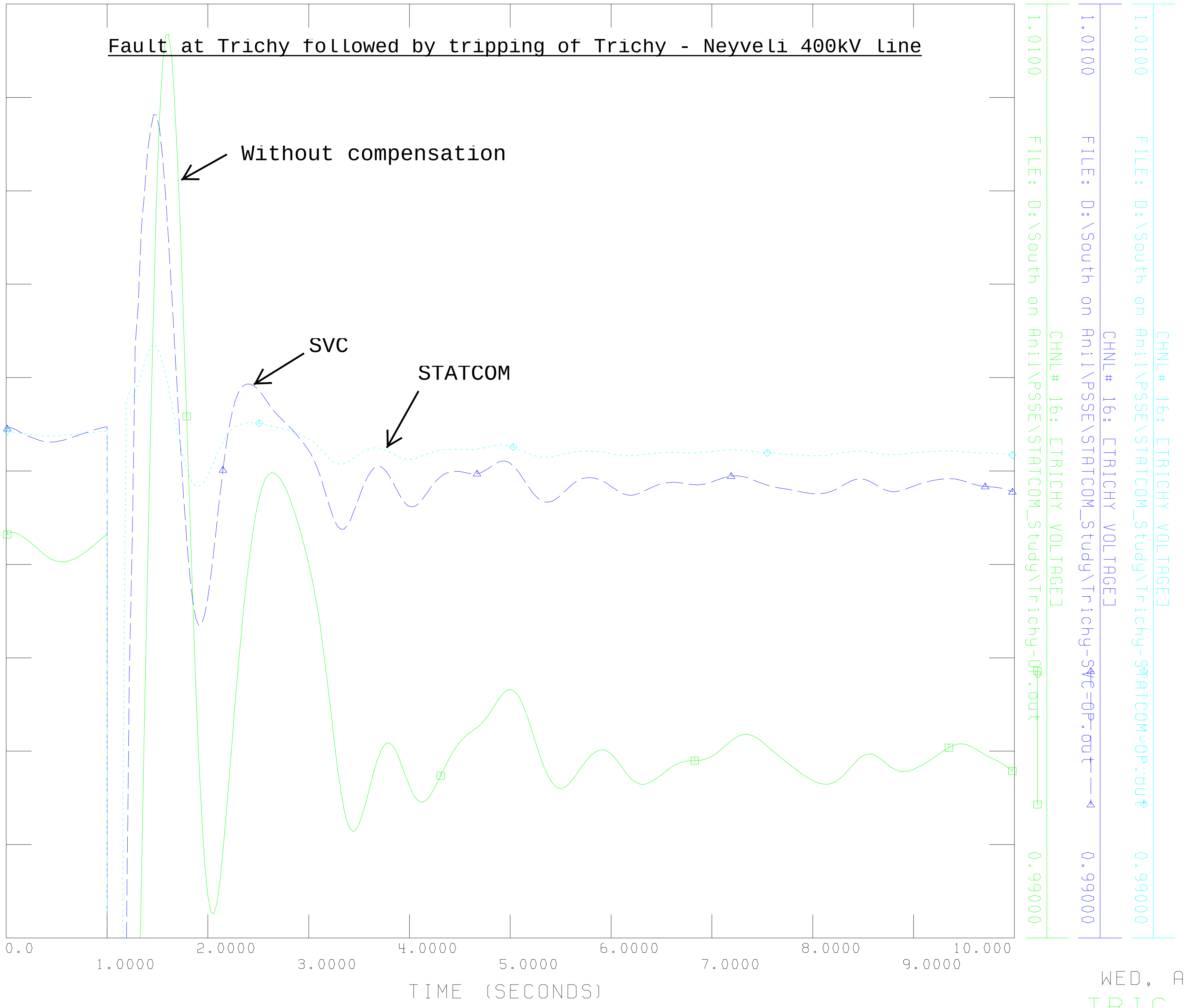


EXHIBIT-8-OP(a)

WED, AUG 07 2013 22:18

TRIC V - OFFPEAK

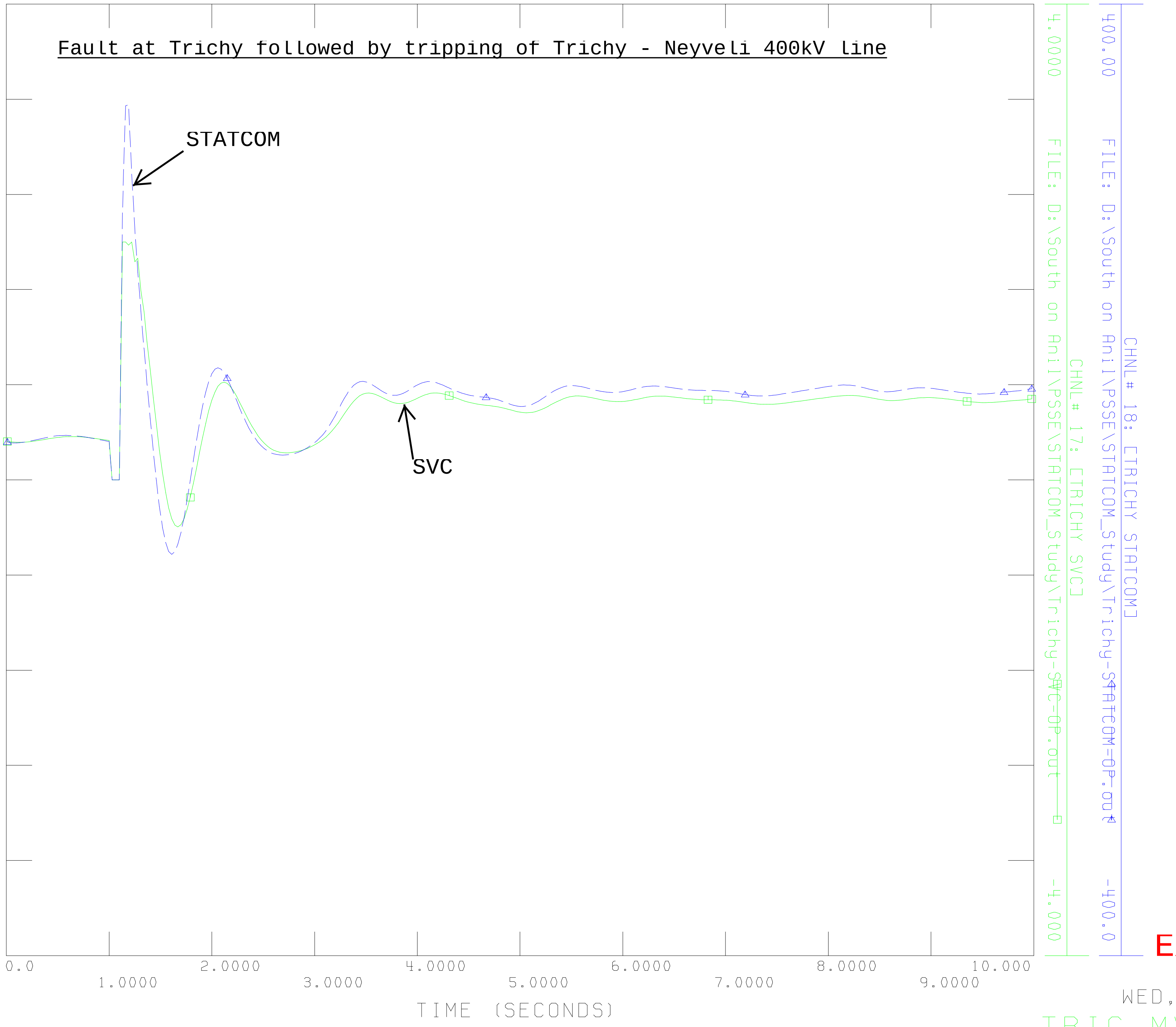
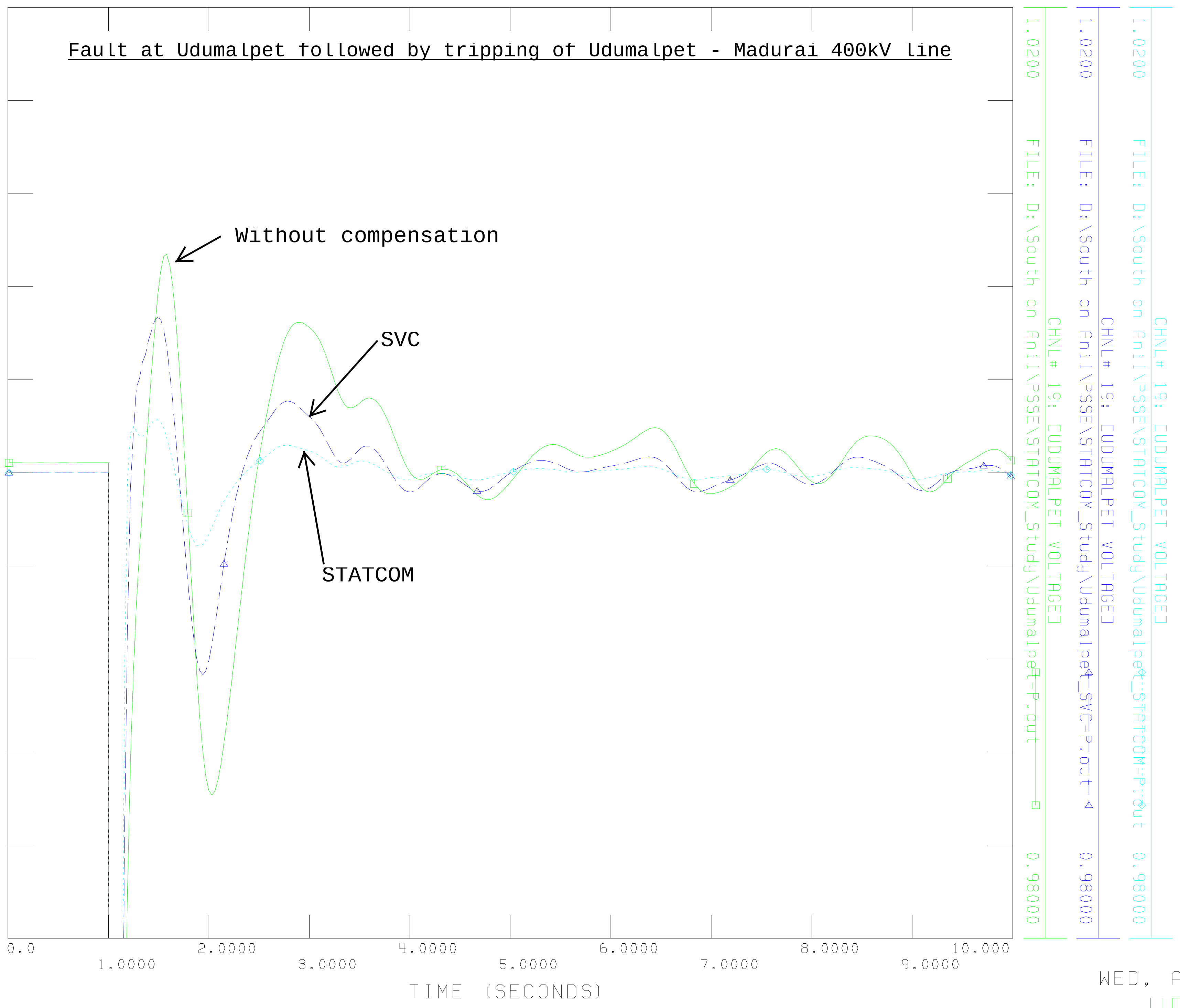


EXHIBIT-8-OP(b)

WED, AUG 07 2013 22:19

TRIC MVAR - OFFPEAK



POWER TECHNOLOGIES, INC.®

EXHIBIT-9-P(a)

WED, AUG 07 2013 22:22

UDUM V - PEAK

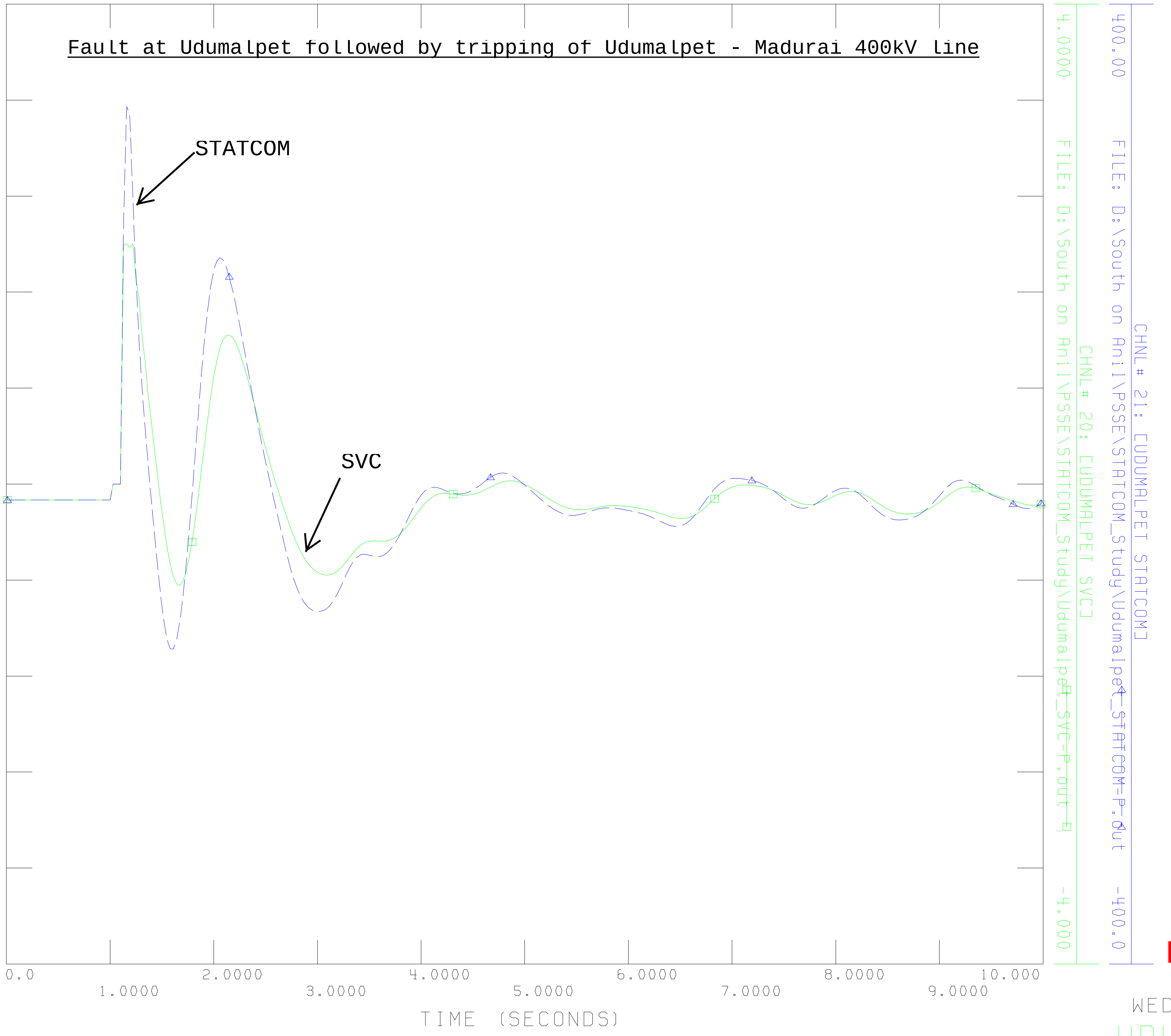


EXHIBIT-9-P(b)

WED, AUG 07 2013 22:24

UDUM MVAR - PEAK

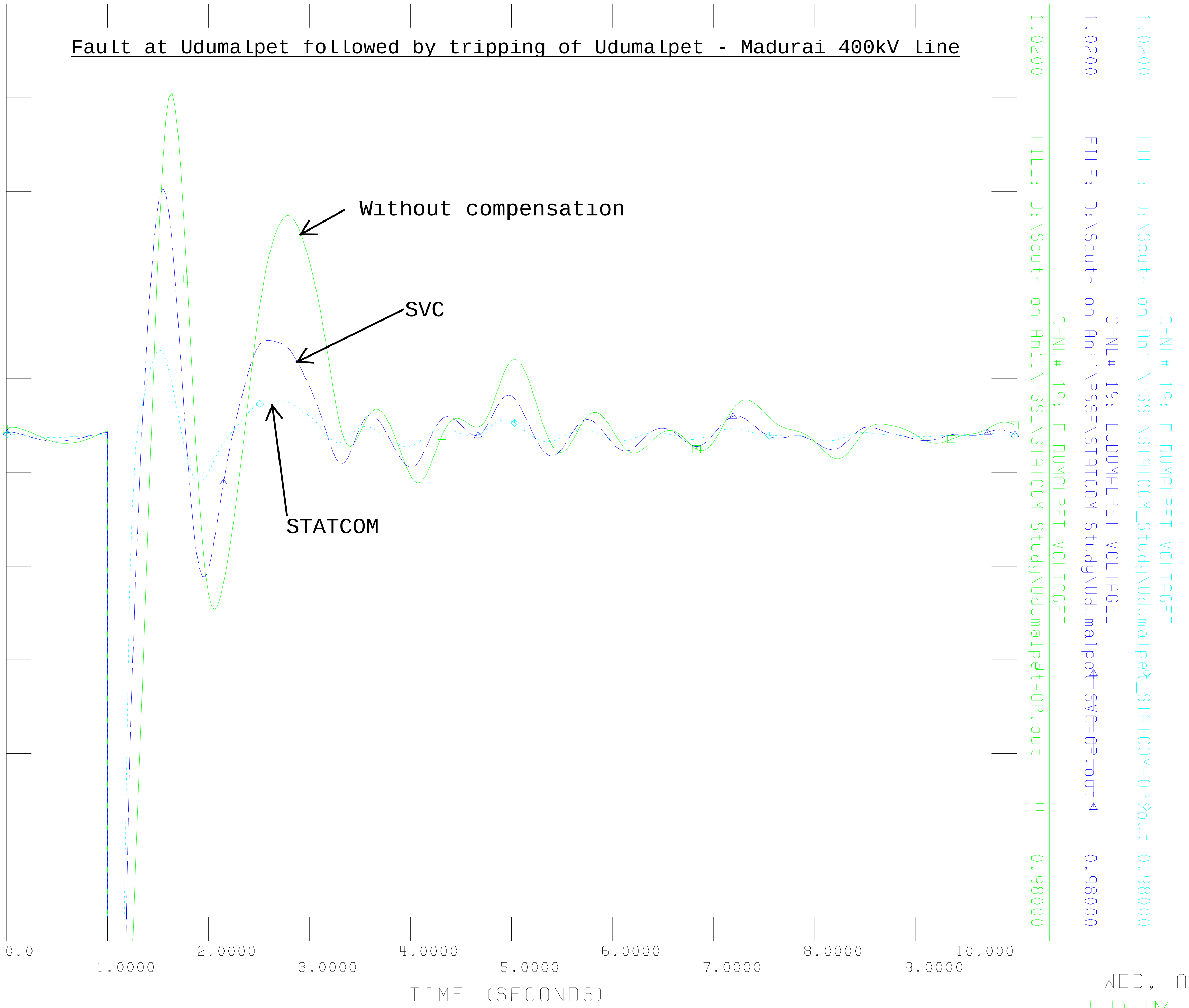


EXHIBIT-9-OP(a)

WED, AUG 07 2013 22:25

UDUM V - OFFPEAK

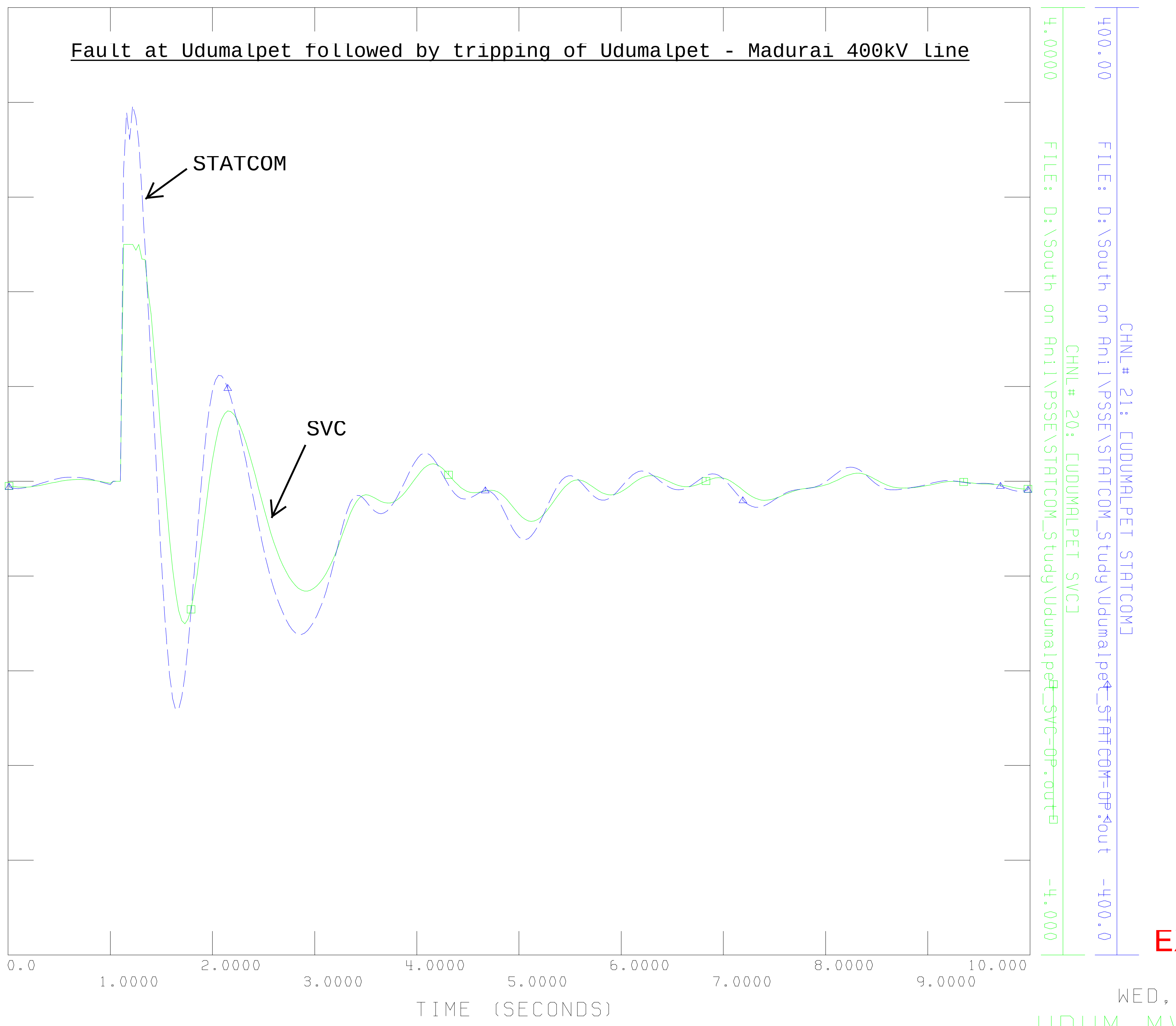
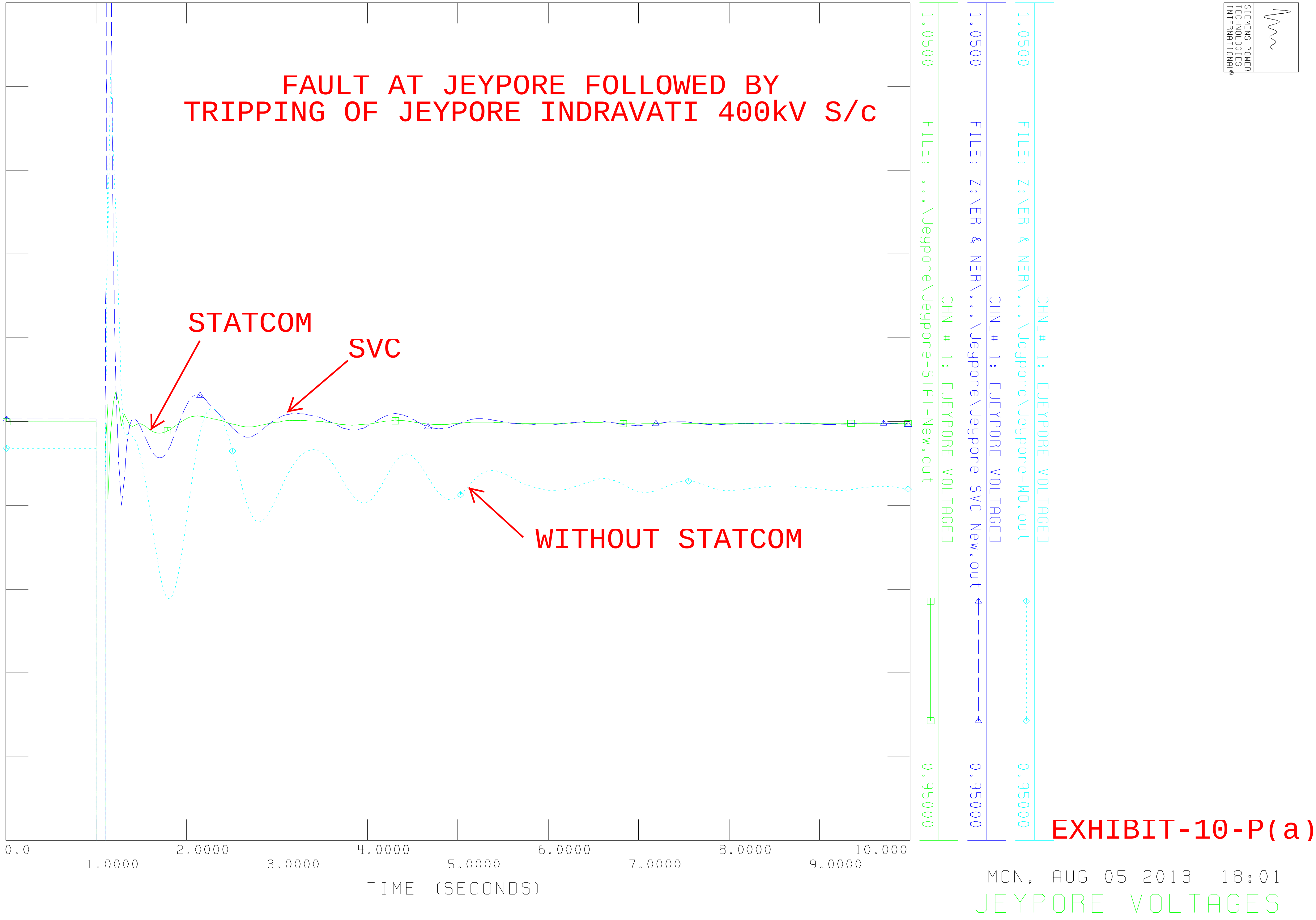


EXHIBIT-9-OP(b)

WED, AUG 07 2013 22:26

UDUM MVAR - OFFPEAK


FAULT AT JEYPORE FOLLOWED BY
TRIPPING OF JEYPORE INDRAVATI 400kV S/c
STATCOM
SVC
WITHOUT STATCOM
0.0
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
9.0000
10.000
TIME (SECONDS)
1.0500
FILE: ...\Jeypore\Jeypore-STAT-New.out
CHNL# 1: [JEYPORE VOLTAGE]
0.95000
1.0500
FILE: Z:\ER & NER\...\Jeypore\Jeypore-SVC-New.out
CHNL# 1: [JEYPORE VOLTAGE]
0.95000
1.0500
FILE: Z:\ER & NER\...\Jeypore\Jeypore-WO.out
CHNL# 1: [JEYPORE VOLTAGE]
0.95000
SIEMENS POWER
TECHNOLOGIES
INTERNATIONAL
EXHIBIT-10-P(a)
MON, AUG 05 2013 18:01
JEYPORE VOLTAGES

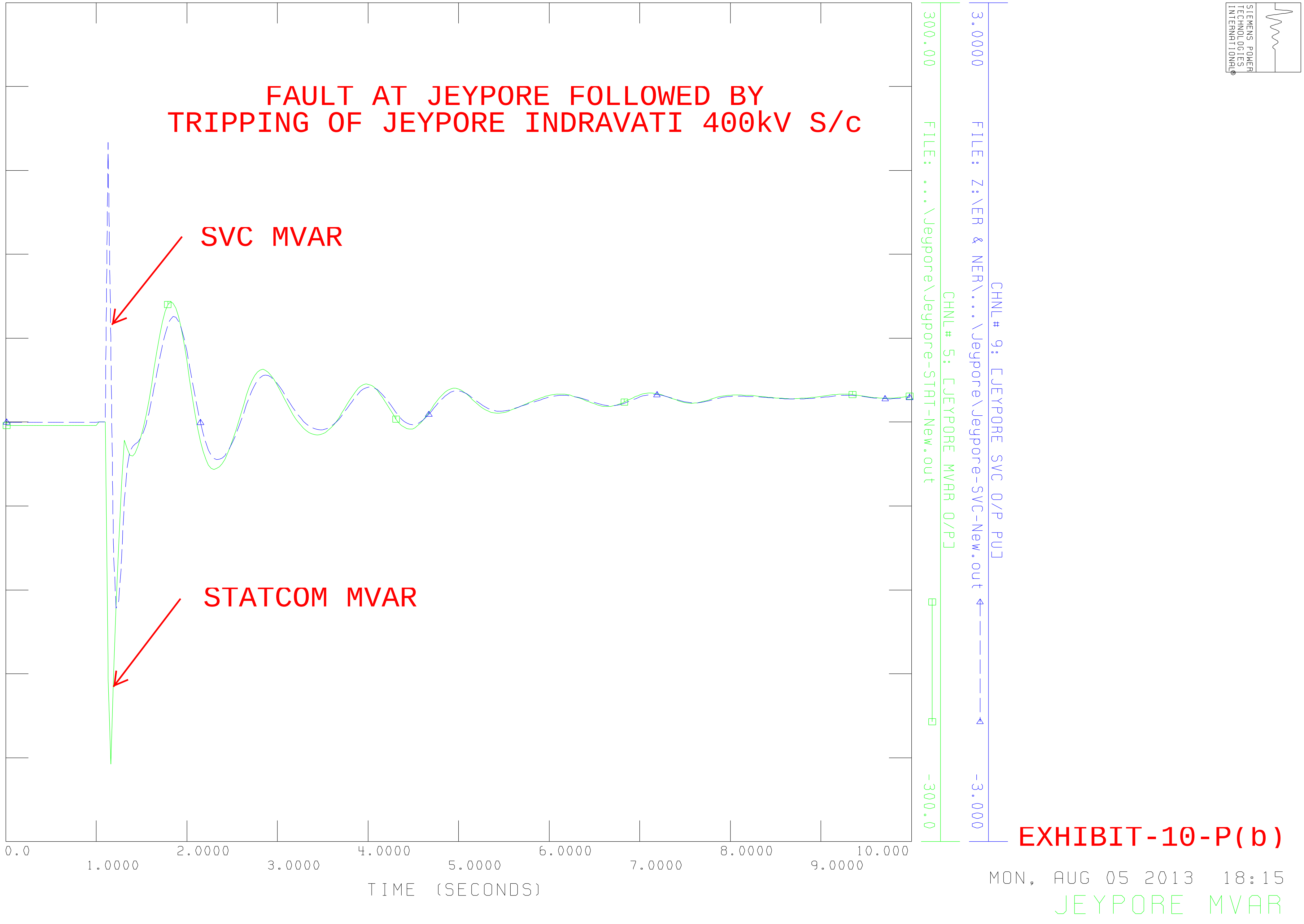


EXHIBIT-10-P(b)

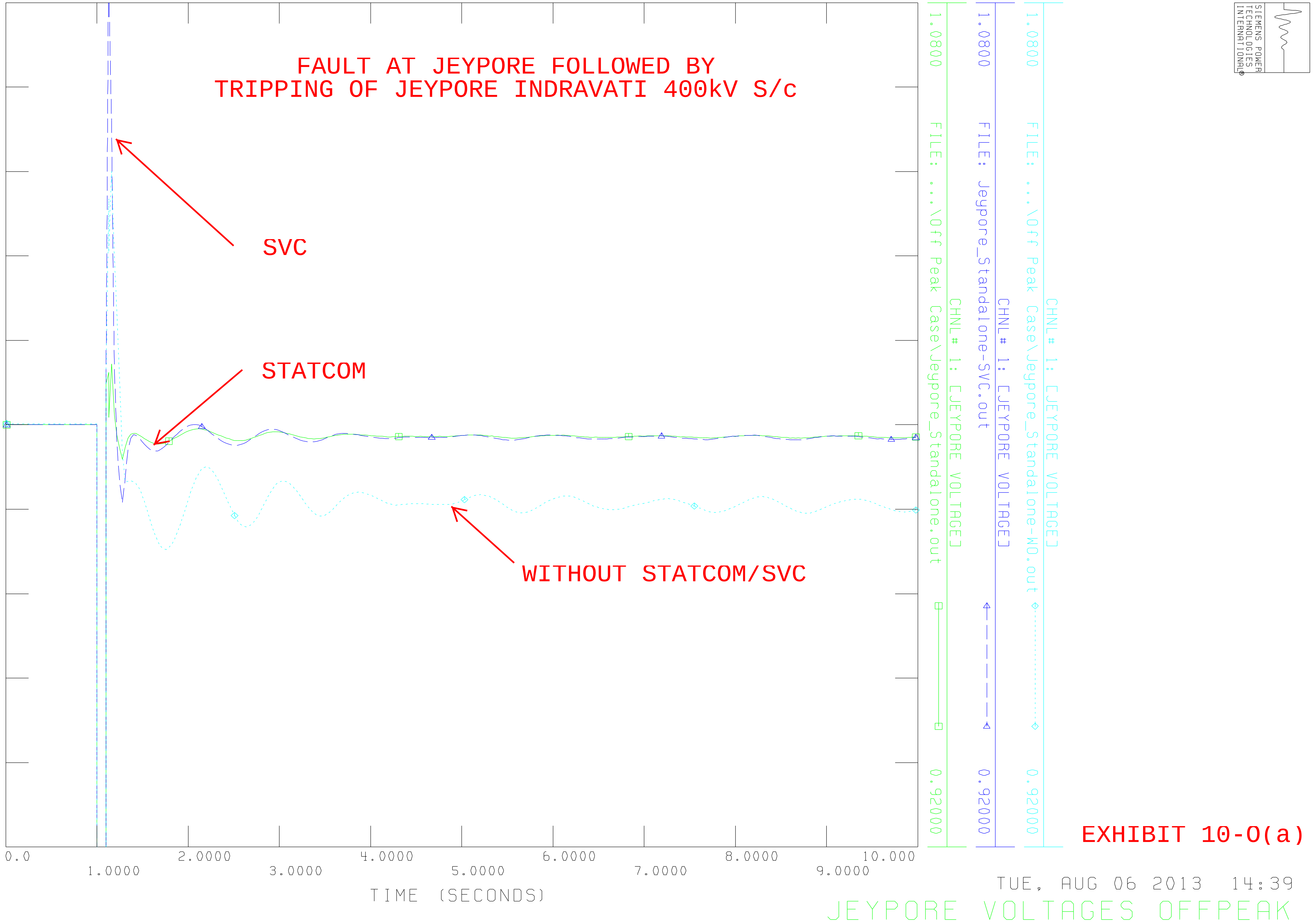


EXHIBIT 10-O(a)

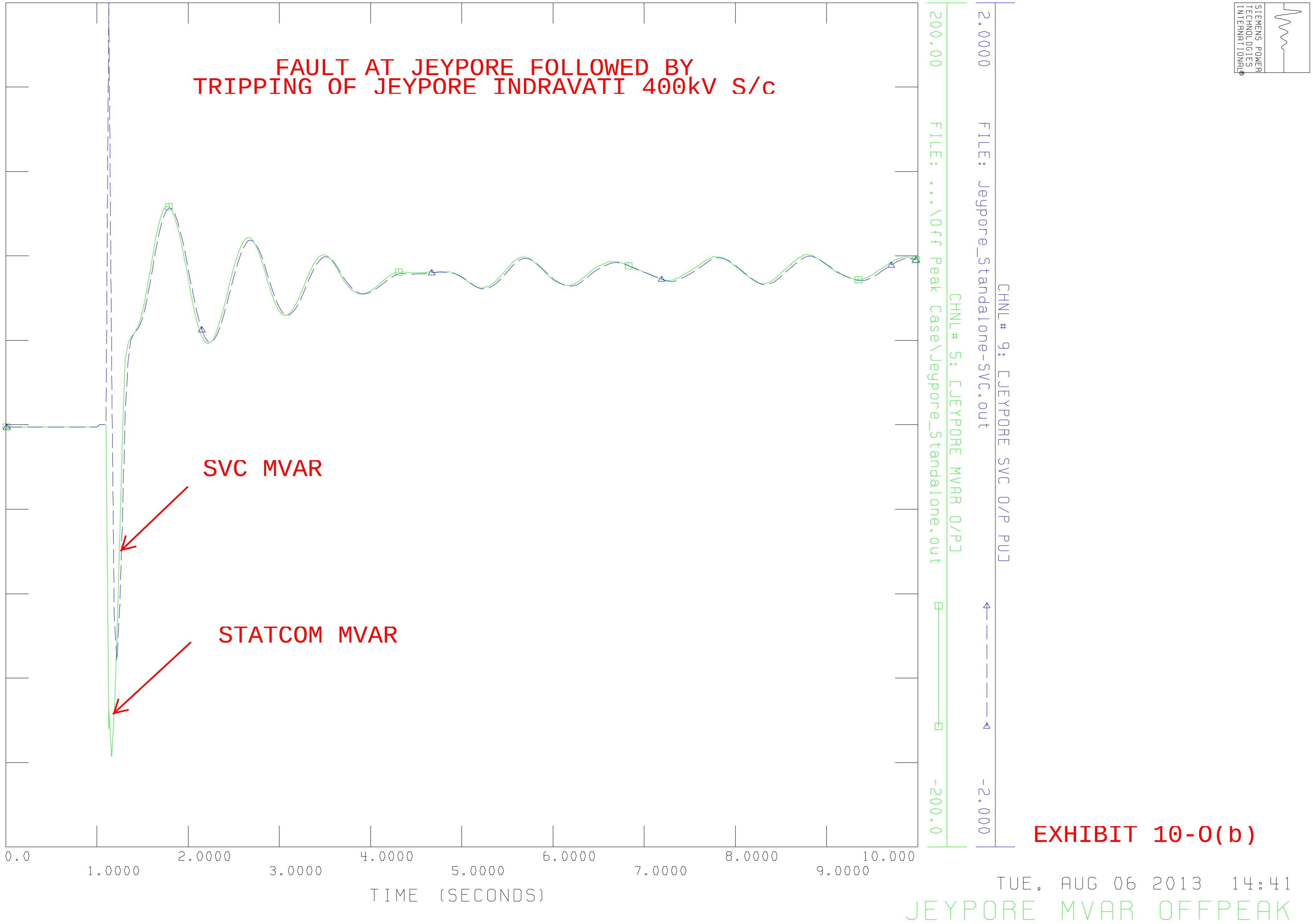


EXHIBIT 10-O(b)

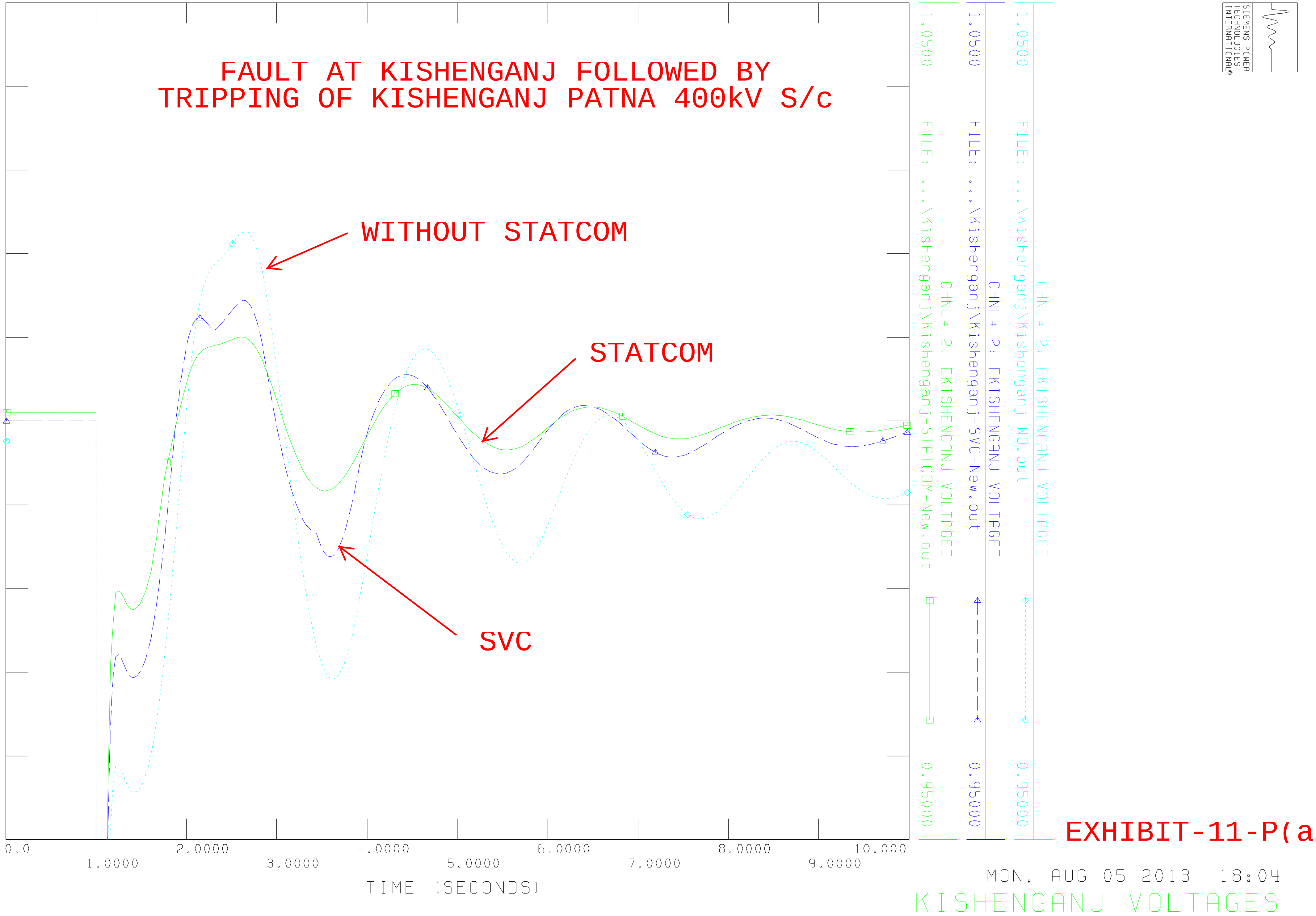
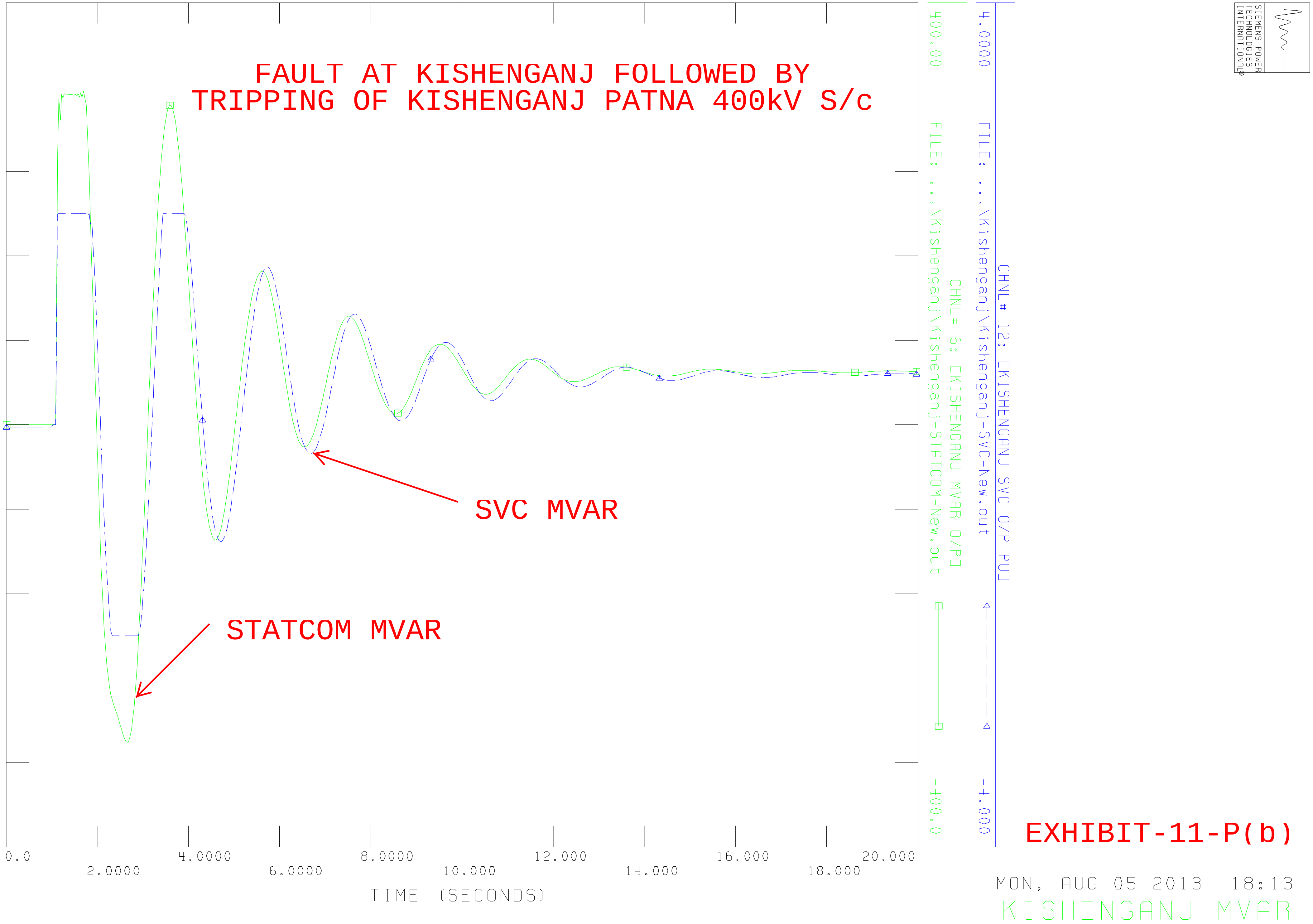
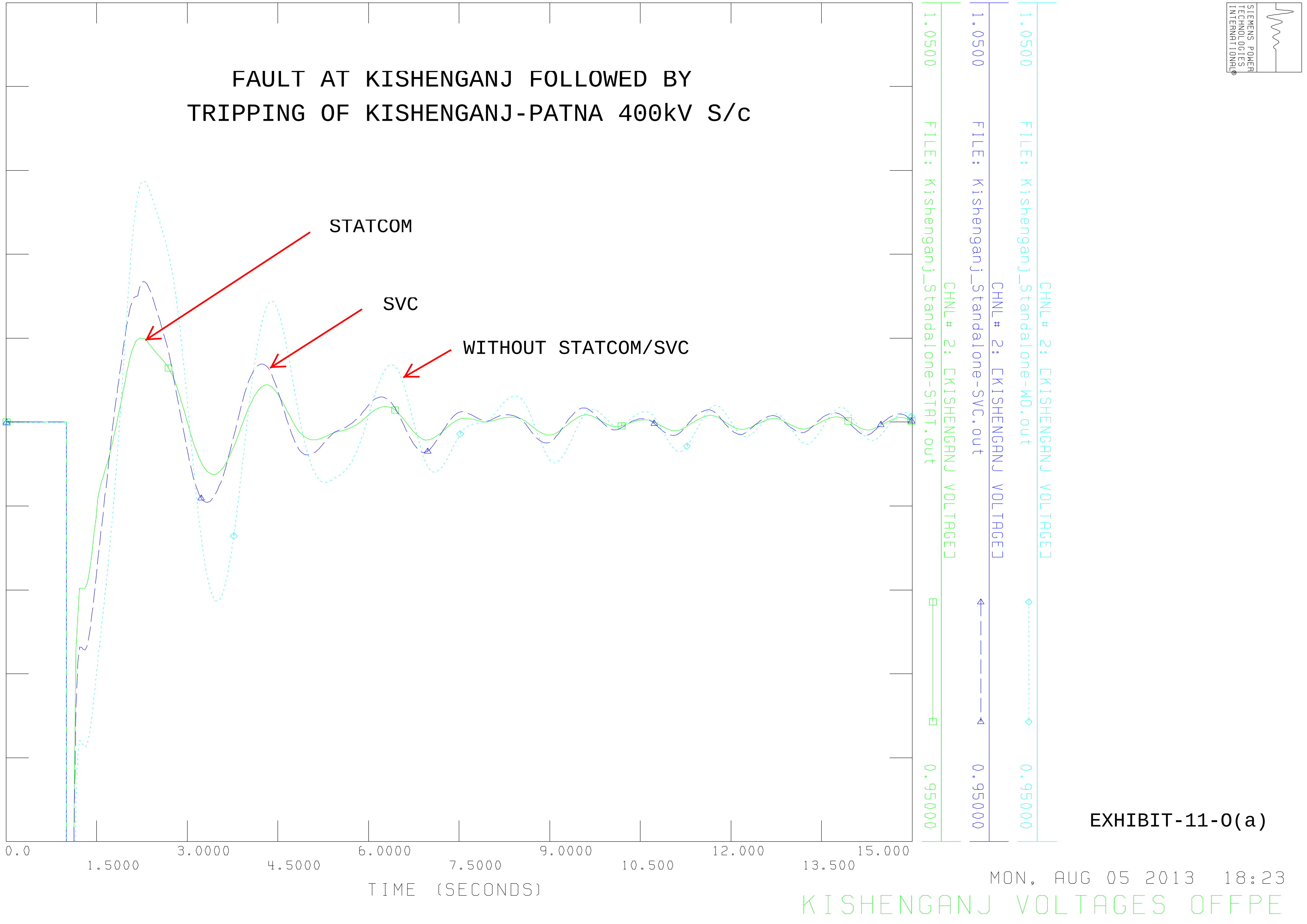


EXHIBIT-11-P(a)


FAULT AT KISHENGANJ FOLLOWED BY
TRIPPING OF KISHENGANJ PATNA 400kV S/c
SVC MVAR
STATCOM MVAR
0.0
2.0000
4.0000
6.0000
8.0000
10.000
12.000
14.000
16.000
18.000
20.000
TIME (SECONDS)
400.00
-400.0
FILE: ...\Kishenganj\Kishenganj-STATCOM-New.out
CHNL# 6: [KISHENGANJ MVAR O/P]
4.0000
-4.000
FILE: ...\Kishenganj\Kishenganj-SVC-New.out
CHNL# 12: [KISHENGANJ SVC O/P PU]
SIEMENS POWER TECHNOLOGIES INTERNATIONAL
EXHIBIT-11-P(b)
MON, AUG 05 2013 18:13
KISHENGANJ MVAR



FAULT AT KISHENGANJ FOLLOWED BY
TRIPPING OF KISHENGANJ-PATNA 400kV S/c
STATCOM
SVC
WITHOUT STATCOM/SVC
0.0
1.5000
3.0000
4.5000
6.0000
7.5000
9.0000
10.500
12.000
13.500
15.000
TIME (SECONDS)
1.0500
FILE: Kishenganj_Standalone-STAT.out
CHNL# 2: [KISHENGANJ VOLTAGE]
0.95000
1.0500
FILE: Kishenganj_Standalone-SVC.out
CHNL# 2: [KISHENGANJ VOLTAGE]
0.95000
1.0500
FILE: Kishenganj_Standalone-WO.out
CHNL# 2: [KISHENGANJ VOLTAGE]
0.95000
SIEMENS POWER TECHNOLOGIES INTERNATIONAL
EXHIBIT-11-O(a)
MON, AUG 05 2013 18:23
KISHENGANJ VOLTAGES OFFPE

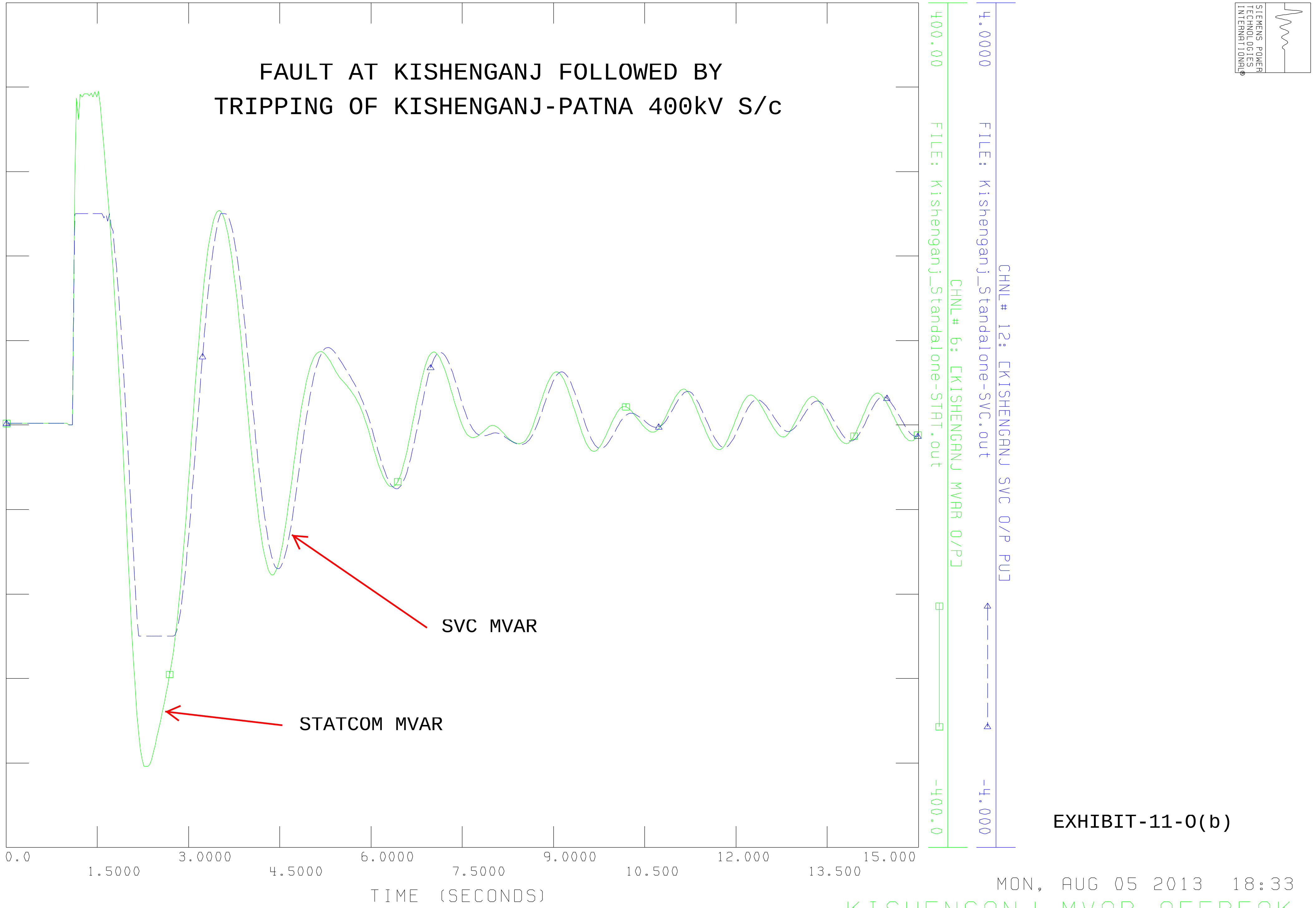


EXHIBIT-11-O(b)

MON, AUG 05 2013 18:33

KISHENGANJ MVAR OFFPEAK

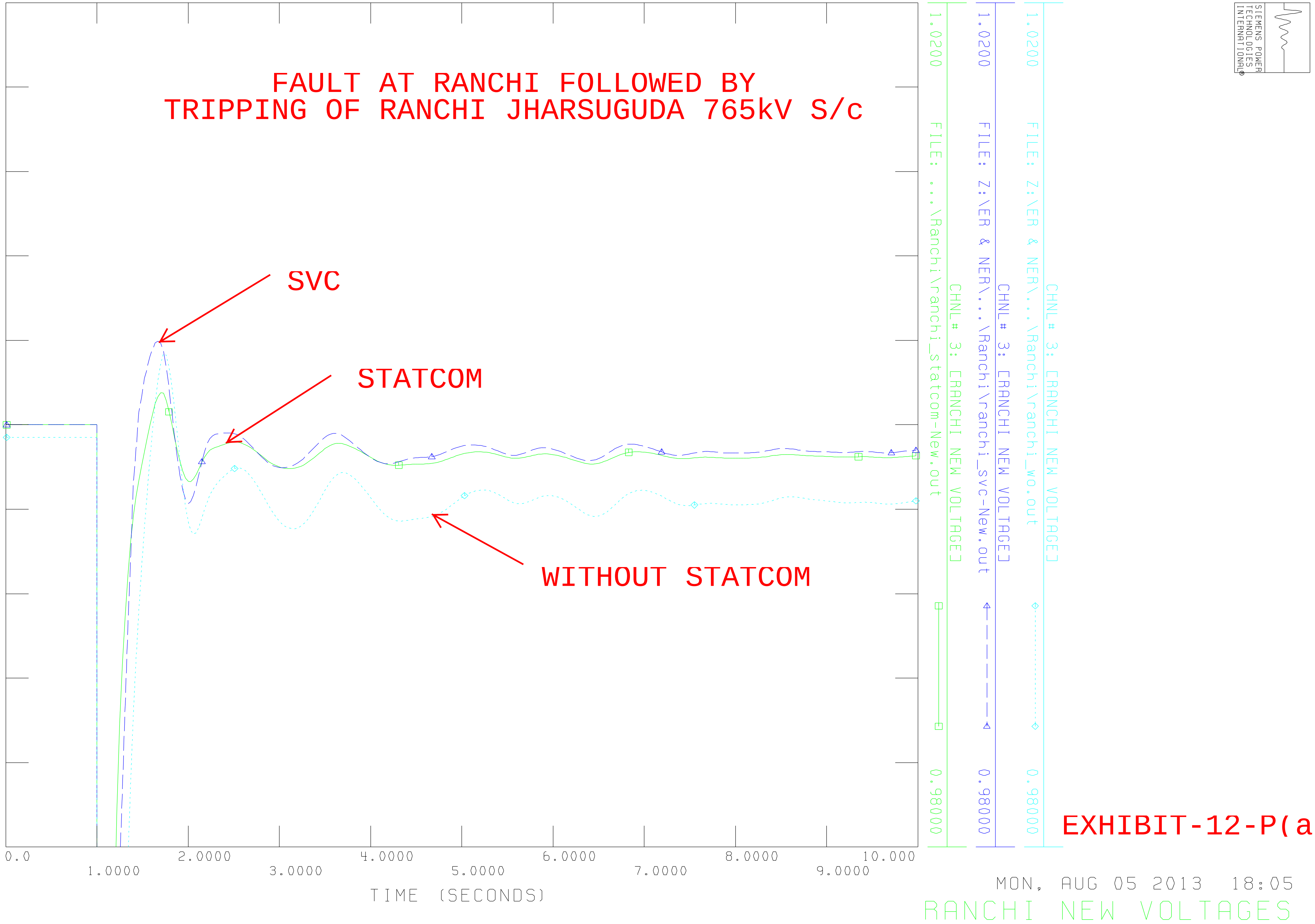


EXHIBIT-12-P(a)

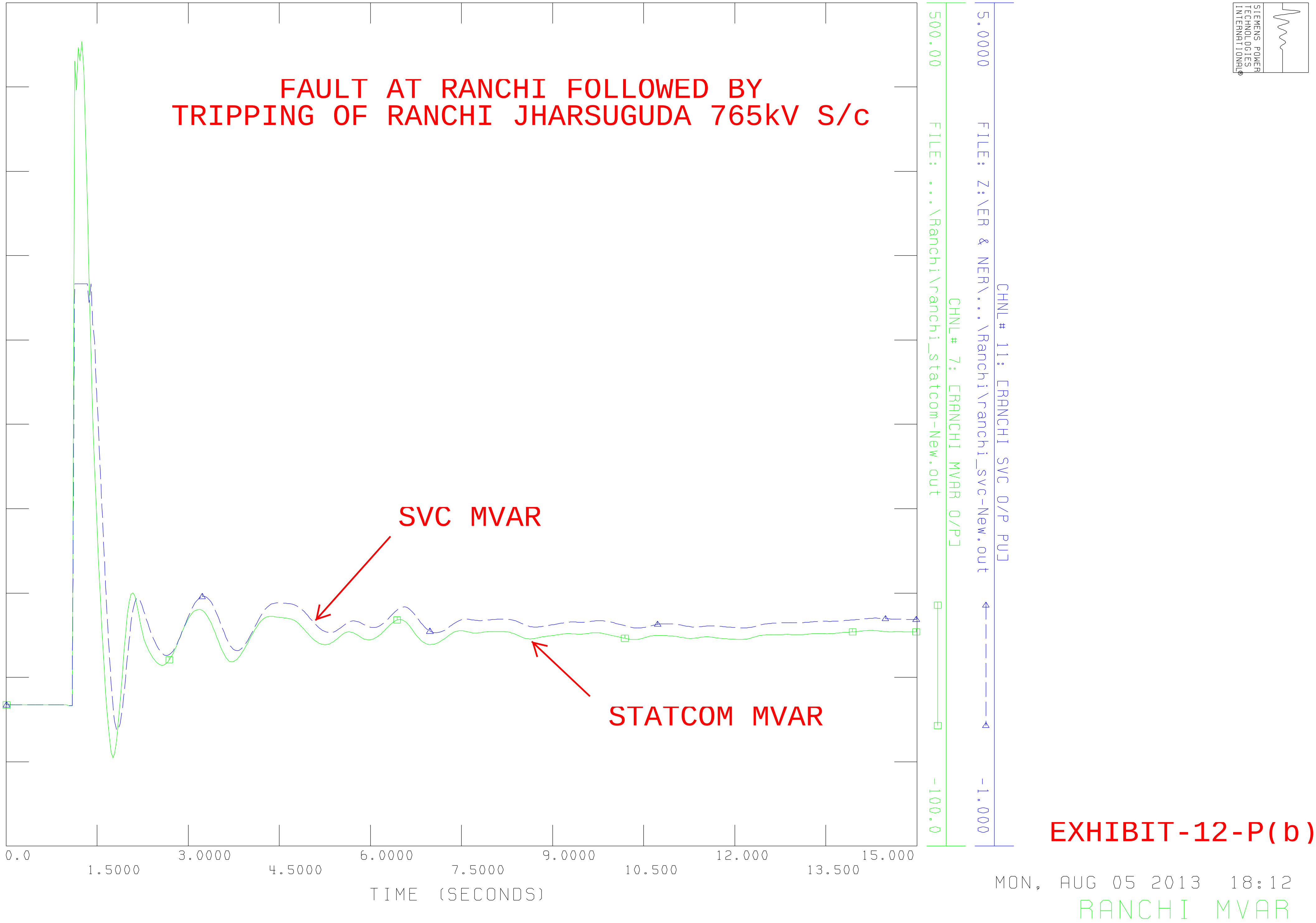


EXHIBIT-12-P(b)

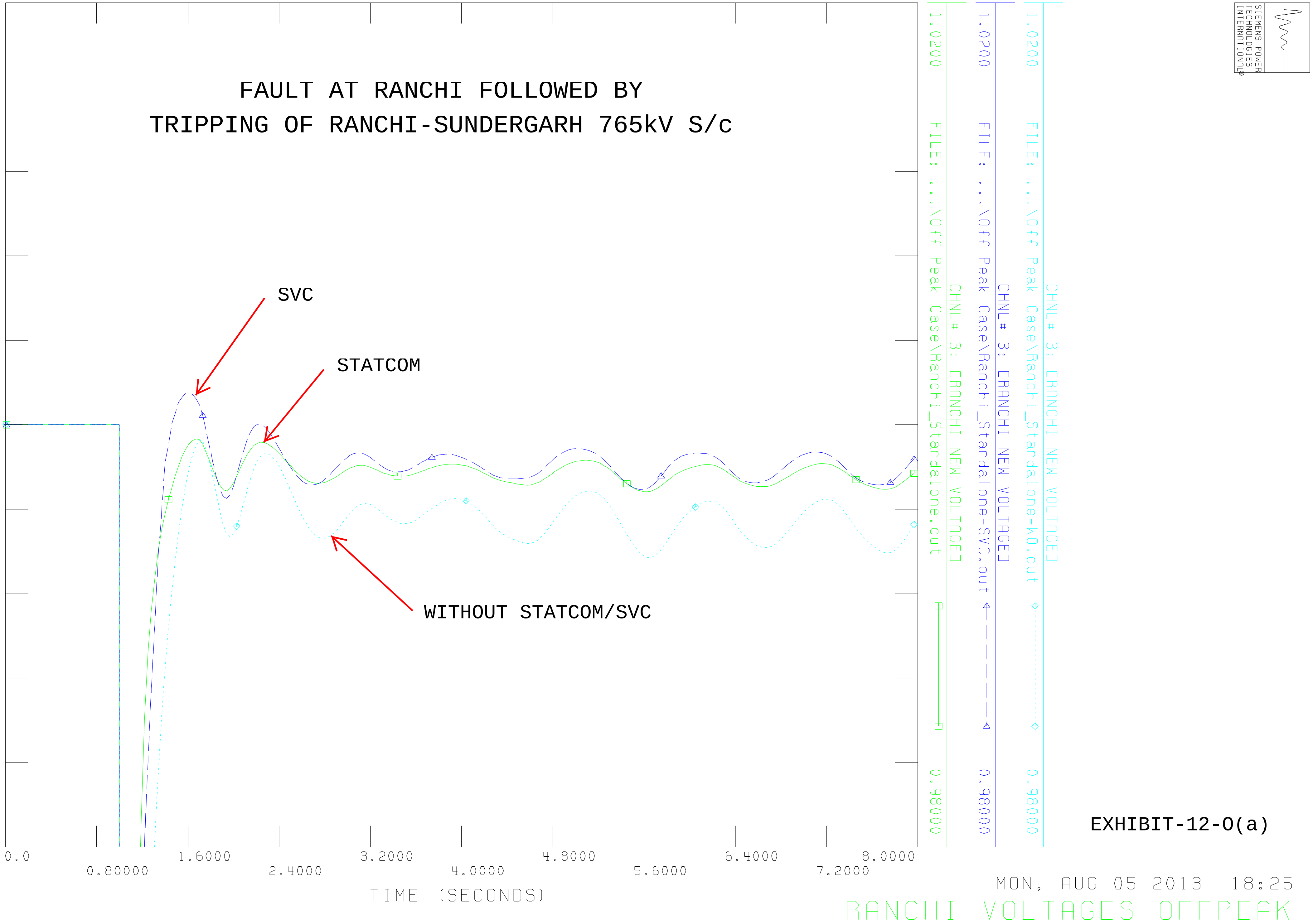


EXHIBIT-12-O(a)

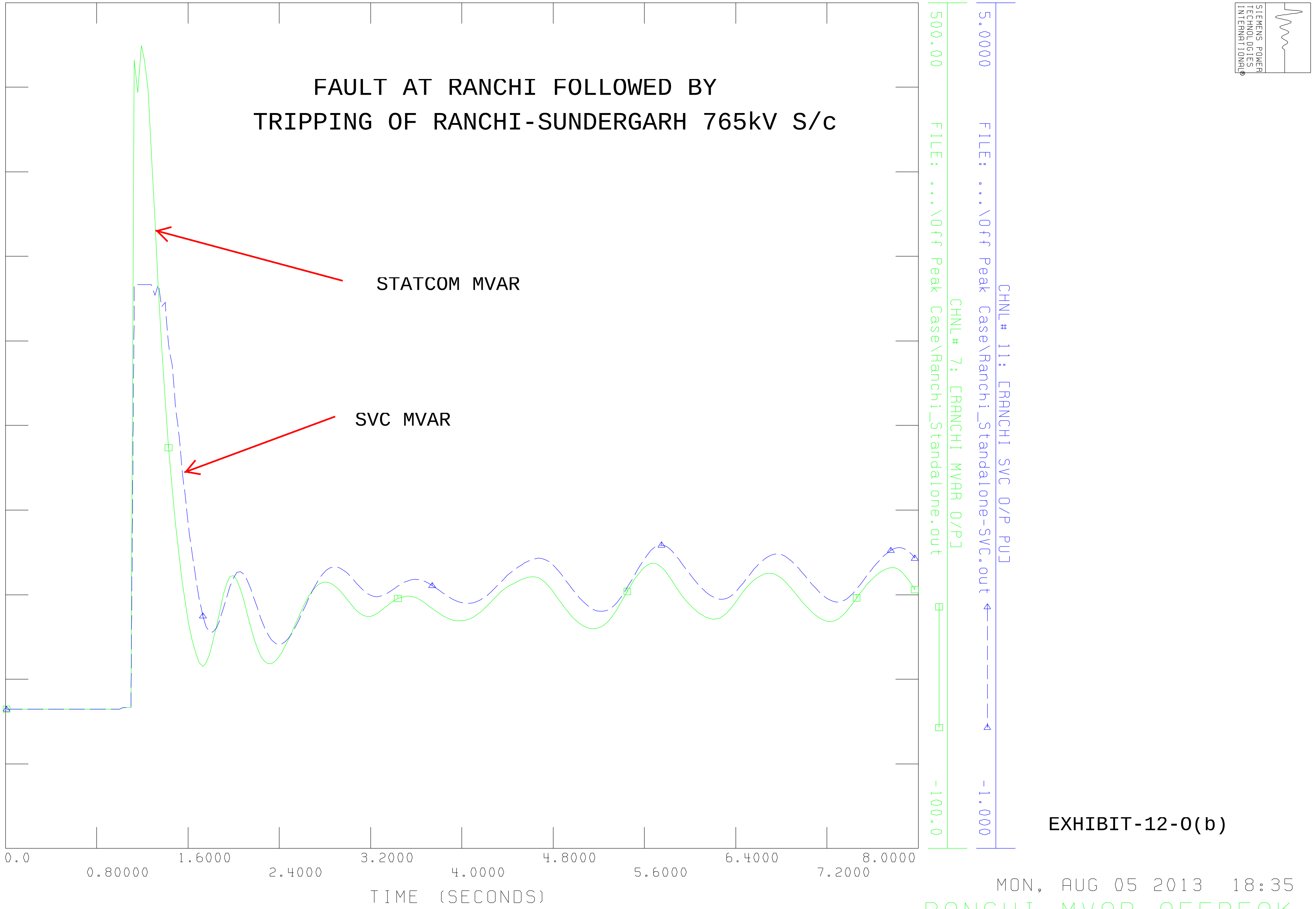


EXHIBIT-12-O(b)

MON, AUG 05 2013 18:35

RANCHI MVAR OFFPEAK

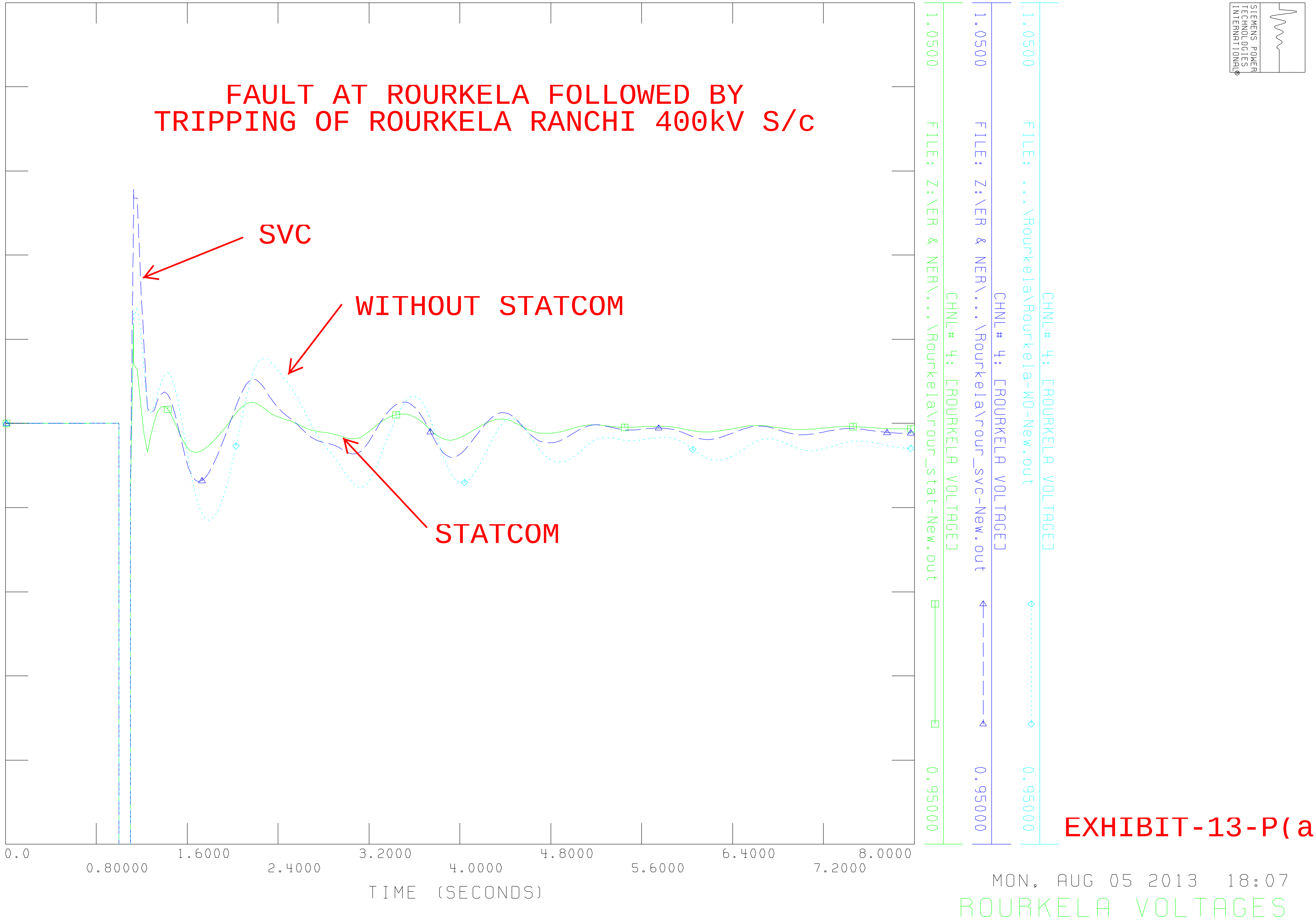
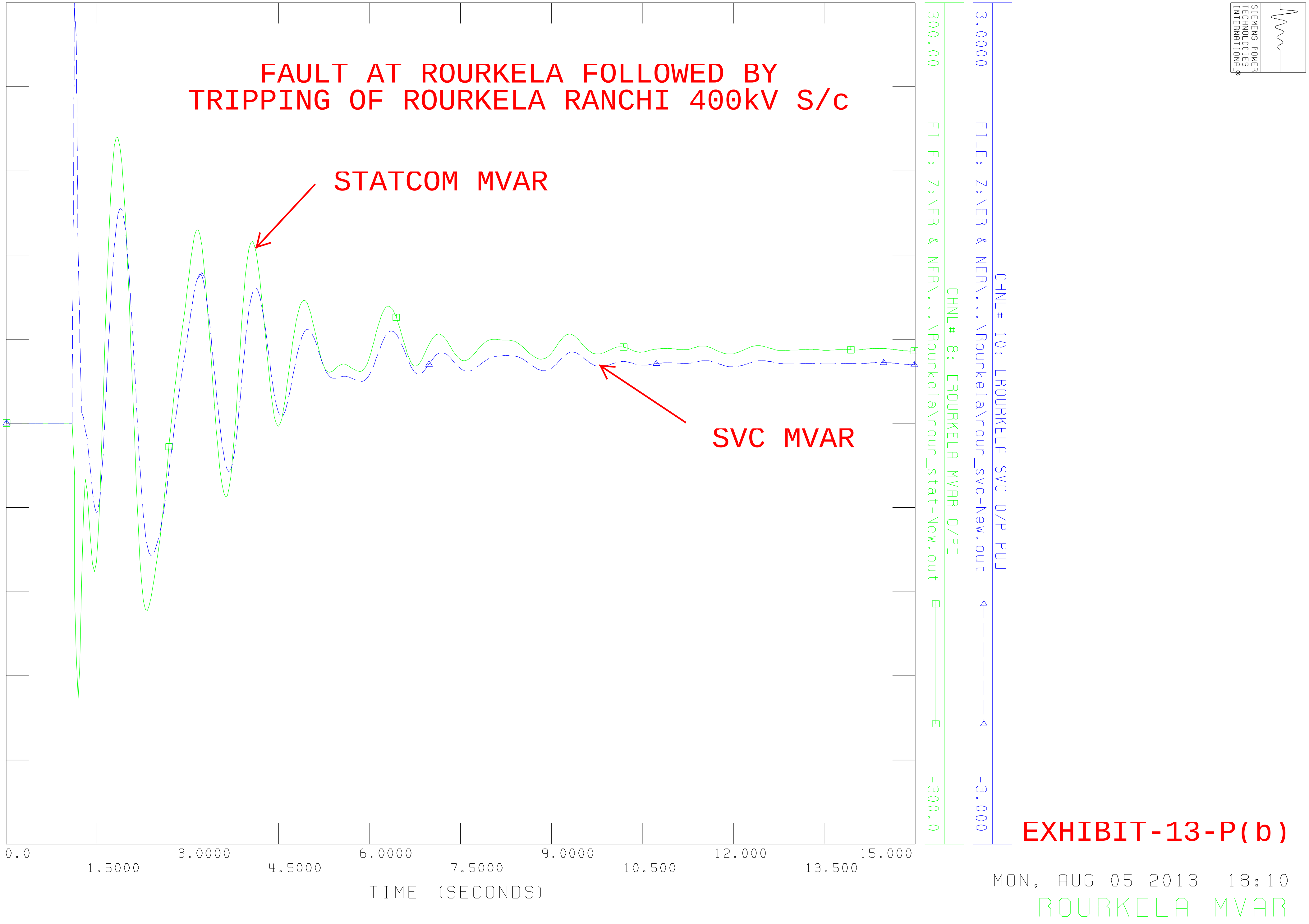


EXHIBIT-13-P(a)


FAULT AT ROURKELA FOLLOWED BY
TRIPPING OF ROURKELA RANCHI 400kV S/c
STATCOM MVAR
SVC MVAR
300.00
FILE: Z:\ER & NER\...\Rourkela\rour_stat-New.out
CHNL# 8: [ROURKELA MVAR O/P]
-300.0
3.0000
FILE: Z:\ER & NER\...\Rourkela\rour_svc-New.out
CHNL# 10: [ROURKELA SVC O/P PU]
-3.000
SIEMENS POWER TECHNOLOGIES INTERNATIONAL
0.0
1.5000
3.0000
4.5000
6.0000
7.5000
9.0000
10.500
12.000
13.500
15.000
TIME (SECONDS)
EXHIBIT-13-P(b)
MON, AUG 05 2013 18:10
ROURKELA MVAR

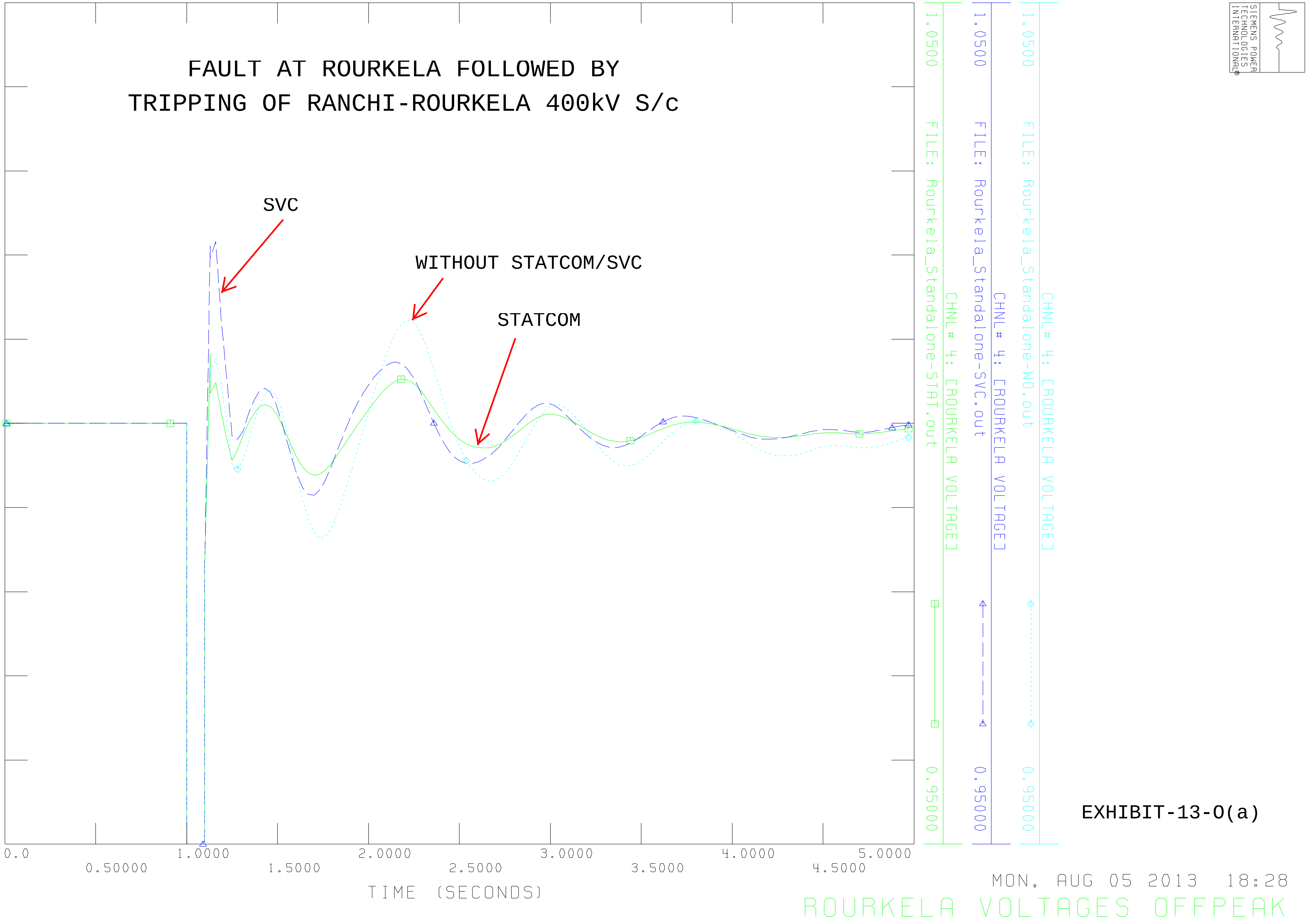


EXHIBIT-13-O(a)

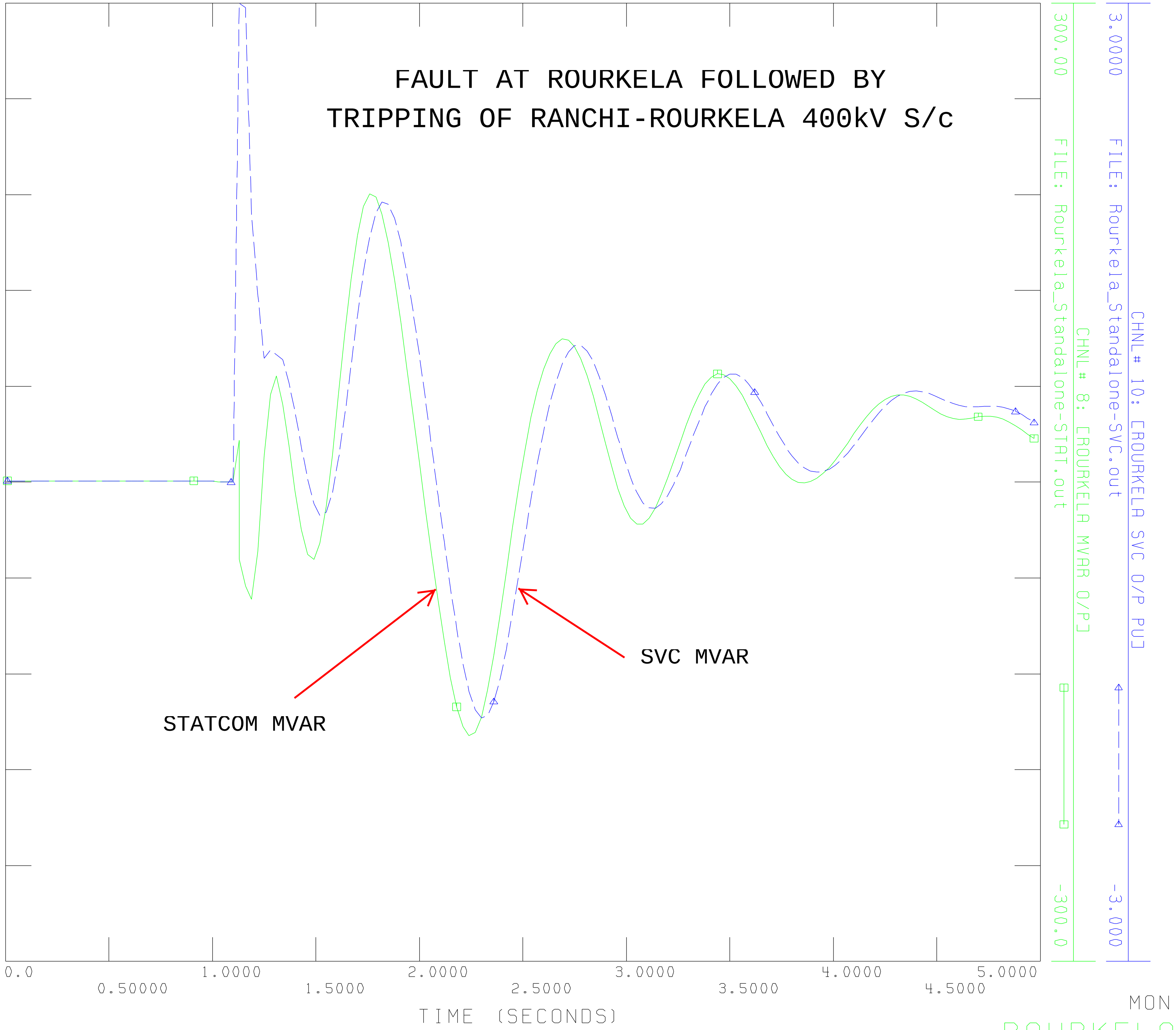


EXHIBIT-13-O(b)

MON, AUG 05 2013 18:38

ROURKELA MVAR OFFPEAK