Testing of Phasor Measurement Units as per IEC&IEEE standards-The Whats and The Hows

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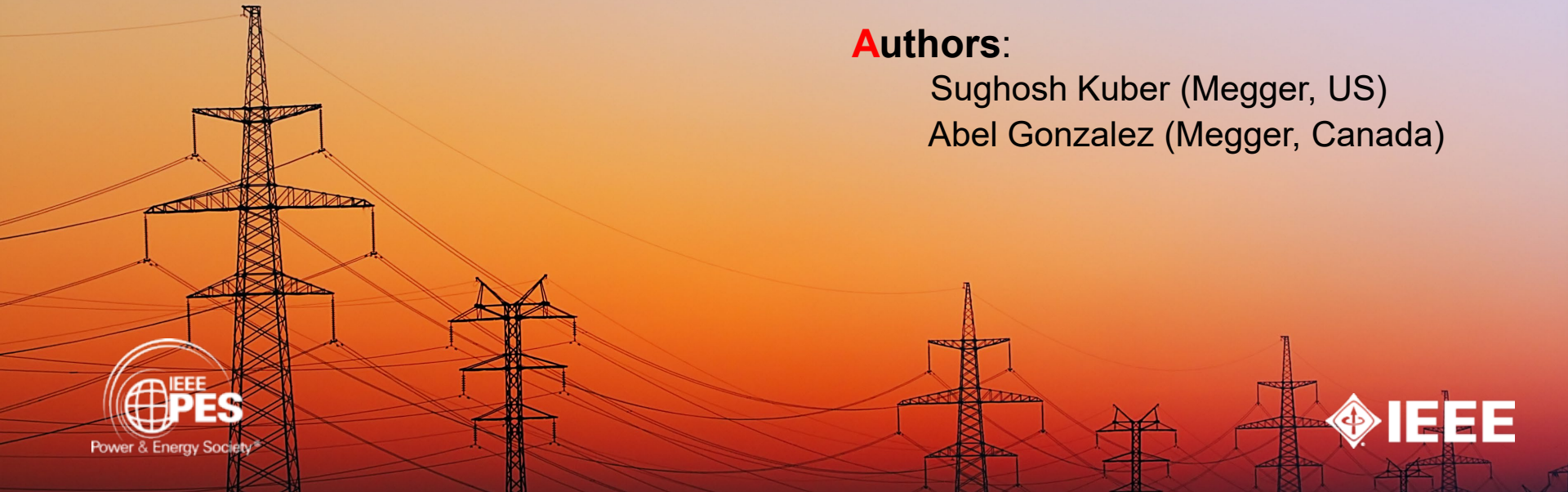


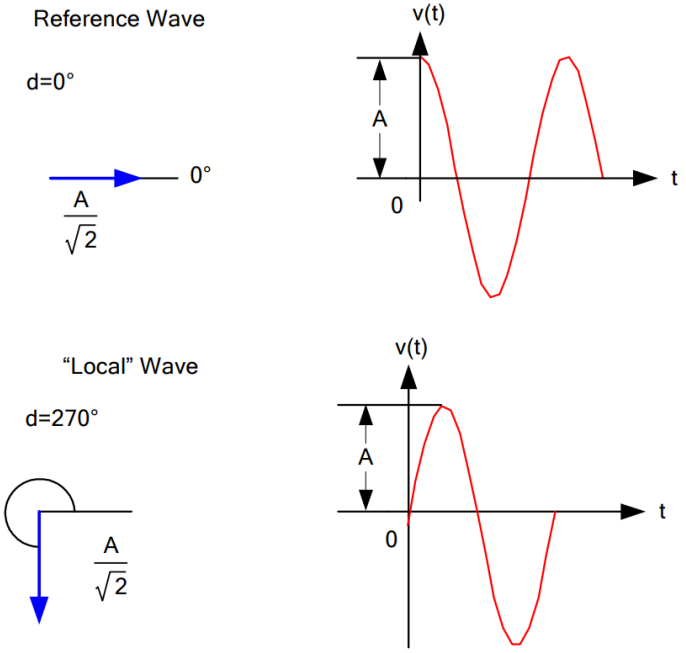
Agenda

- Introduction to PMU and Synchrophasors
- IEEE 60255-118-1
- Test Considerations
- Test Setup
- Test Cases
- Results & Analysis
- Summary/Conclusions

Introduction to Synchrophasors

Synchrophasors

- Phasor Data
- Importance of Synchronization



Reference - https://selinc.com/api/download/3685/

Phasor Measurement Units

- Phasor Data Capture
- Synchronized manner
- Reference Time Signal

PMU Applications

- Wide area protection schemes
- Disturbance analysis
- Power system health monitoring
- Model Validation
- Post-event analysis

IEEE/IEC 60255-118-1 Standard

- Standard for synchrophasor measurement
- Requirement for time tagging, synchronization, evaluation methods and compliance tests
- Testing considerations, steady state and dynamic compliance
- Measurement response time, reporting latency

Total Vector Error (TVE)

- TVE - measure of difference between a measured quantity from PMU when compared with a reference quantity

$$\mathrm{TVE}(n) = \sqrt{\frac{(\hat{X}_r(n) - X_r(n))^2 + (\hat{X}_i(n) - X_i(n))^2}{(X_r(n))^2 + (X_i(n))^2}} \qquad (9)$$

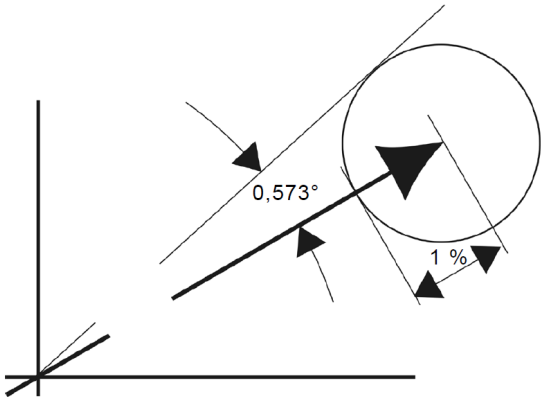
where

$\hat{X}_r(n)$ and $\hat{X}_i(n)$	are the real and imaginary PMU estimates at report time n;
$X_r(n)$ and $X_i(n)$	are the real and imaginary reference values at report time n;
n	is the report number representing the report time (the n^{th} report in a series of discrete reports).

Reference - https://standards.ieee.org/ieee/60255-118-1/5724/

TVE Tolerance

- TVE – considered for all performance tests is about 1%
- Max Magnitude error – 1 % when phase error is 0
- Max Phase error – 0.573 when mag error is 0



Reference - https://standards.ieee.org/ieee/60255-118-1/5724/

Test Considerations

- Performance class – P class & M class
- Standard reference conditions
- Some of the standard reference conditions for all tests are as follows –
  - Nominal voltage
  - Nominal current
  - Nominal frequency
  - Constant voltage, current, phase and frequency
  - signal THD+N < 0,2 % of the fundamental (where N = noise);
  - all interfering signals < 0,2 % of the fundamental

Steady State Compliance Testing

- Comparison of synchrophasor, frequency and ROCOF measurement data with the reference values.
- Injection of test signals not less than 5 seconds.
- Same tests can be used for frequenct and ROCOF tests.

Steady State Synchrophasor requirements

Influence quantity	Reference condition	Minimum range of influence quantity over which PMU shall be within given TVE limit			
		Performance – P class		Performance – M class	
		Range	Max. TVE %	Range	Max. TVE %
Signal frequency	Frequency = f_0 ($f_{nominal}$)	± 2,0 Hz	1	± 2,0 Hz for $F_s < 10$ ± F_s/5 for $10 \leq F_s < 25$ ± 5,0 Hz for $F_s \geq 25$	1
Voltage signal magnitude	100 % rated	80 % to 120 % rated	1	10 % to 120 % rated	1
Current signal magnitude	100 % rated	10 % to 200 % rated	1	10 % to 200 % rated	1

Steady State Compliance Testing

Influence quantity	Reference condition	Error requirements for compliance			
		P class		M class	
Signal frequency	Frequency = f_0 ($f_{nominal}$) Phase angle constant	Range: f_0 ± 2,0 Hz		Range: f_0 ± 2,0 Hz for $F_s \leq 10$ ± F_s/5 for $10 \leq F_s < 25$ ± 5,0 Hz for $F_s \geq 25$	
		Max. |FE|	Max. |RFE|	Max. |FE|	Max. |RFE|
		0,005 Hz	0,4 Hz/s	0,005 Hz	0,1 Hz/s

Dynamic Compliance Testing

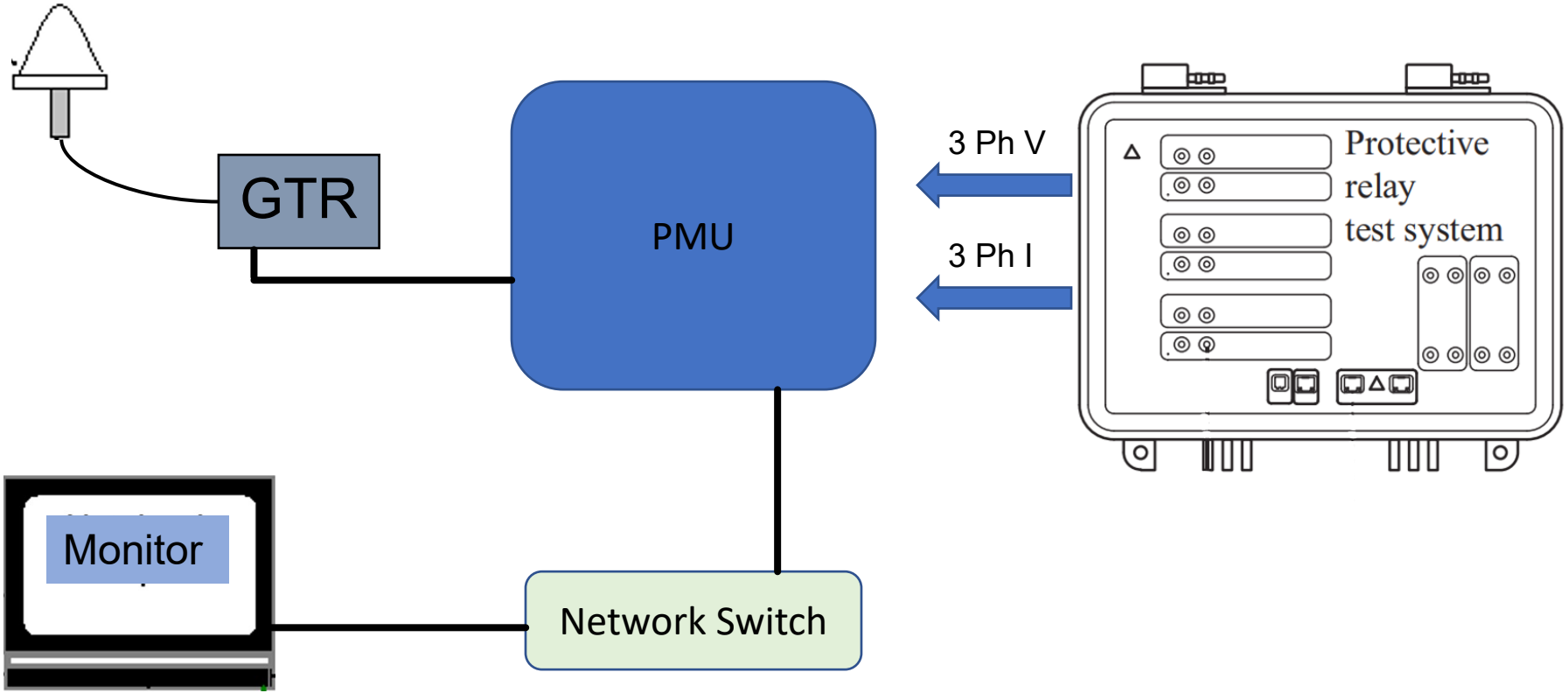
- Modulation of balanced three phase inputs
- Amplitude and phase modulation
- Frequency modulation

Modulation level	Reference condition	Minimum range of influence quantity over which PMU shall be within given TVE limit			
		P class		M class	
		Range	Max. TVE	Range	Max. TVE
k_x = 0,1, k_a = 0	100 % rated signal magnitude, $f_{nominal}$	Modulation frequency 0,1 to lesser of F_s/10 or 2 Hz	3 %	Modulation frequency 0,1 to lesser of F_s/5 or 5 Hz	3 %
k_x = 0, k_a = 0,1	100 % rated signal magnitude, $f_{nominal}$		3 %		3 %

Dynamic Compliance Testing

Frequency and ROCOF performance limits	Error requirements for compliance					
	P class			M class		
Reporting rate F_s Hz	F_r Hz	Max. |FE| Hz	Max. |RFE| Hz/s	F_r Hz	Max. |FE| Hz	Max. |RFE| Hz/s
10	1	0,03	0,6	2	0,12	2,3
12	1,2	0,04	0,8	2,4	0,14	3,3
15	1,5	0,05	1,3	3	0,18	5,1
20	2	0,06	2,3	4	0,24	9,0
25	2	0,06	2,3	5	0,30	14
30	2	0,06	2,3	5	0,30	14
50	2	0,06	2,3	5	0,30	14
60	2	0,06	2,3	5	0,30	14
100	2	0,06	2,3	5	0,30	14
120	2	0,06	2,3	5	0,30	14
Formulas	$\min(F_s/10;2)$	$0,03 \times F_r$	$0,18 \times \pi \times F_r^2$	$\min(F_s/5;5)$	$0,06 \times F_r$	$0,18 \times \pi \times F_r^2$

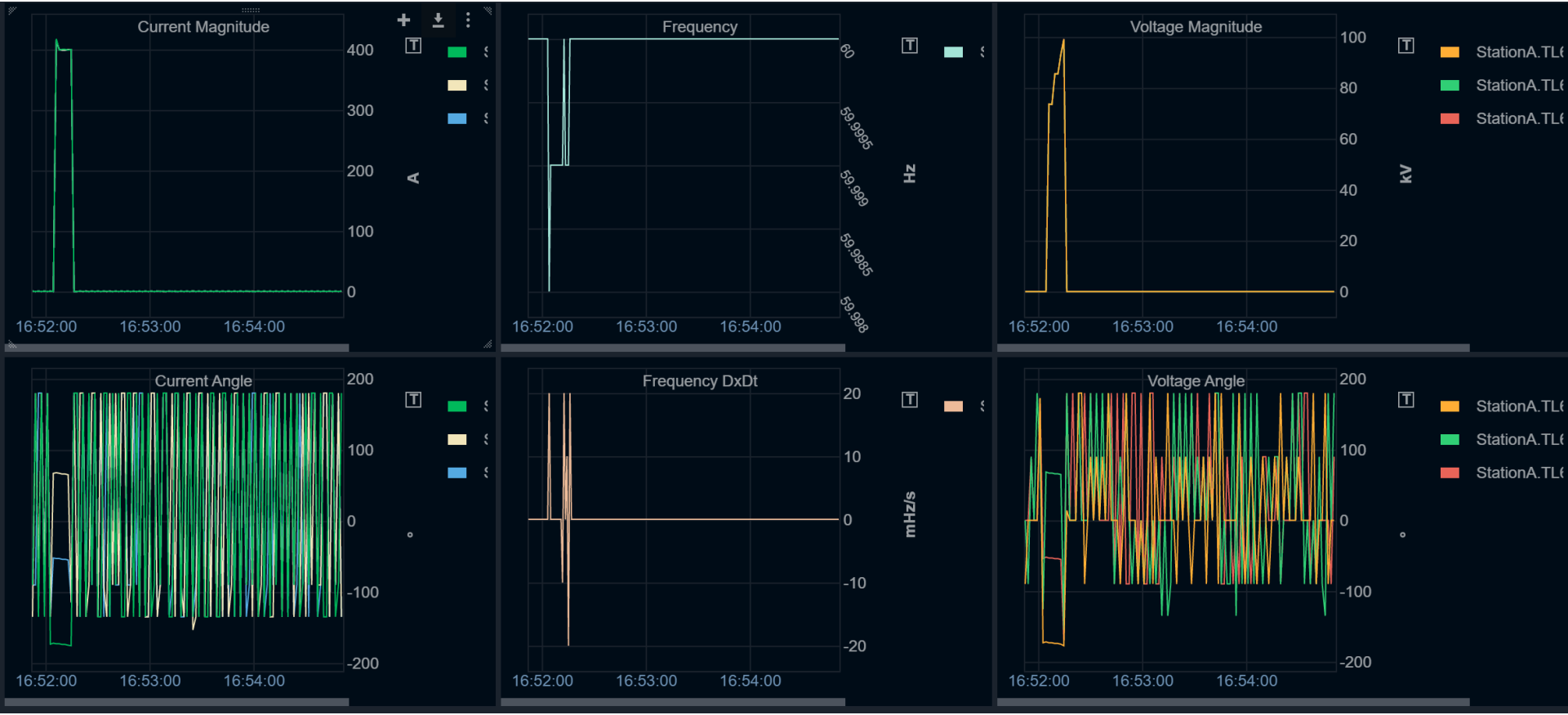
Test Setup


GTR
PMU
3 Ph V
3 Ph I
Protective
relay
test system
Monitor
Network Switch

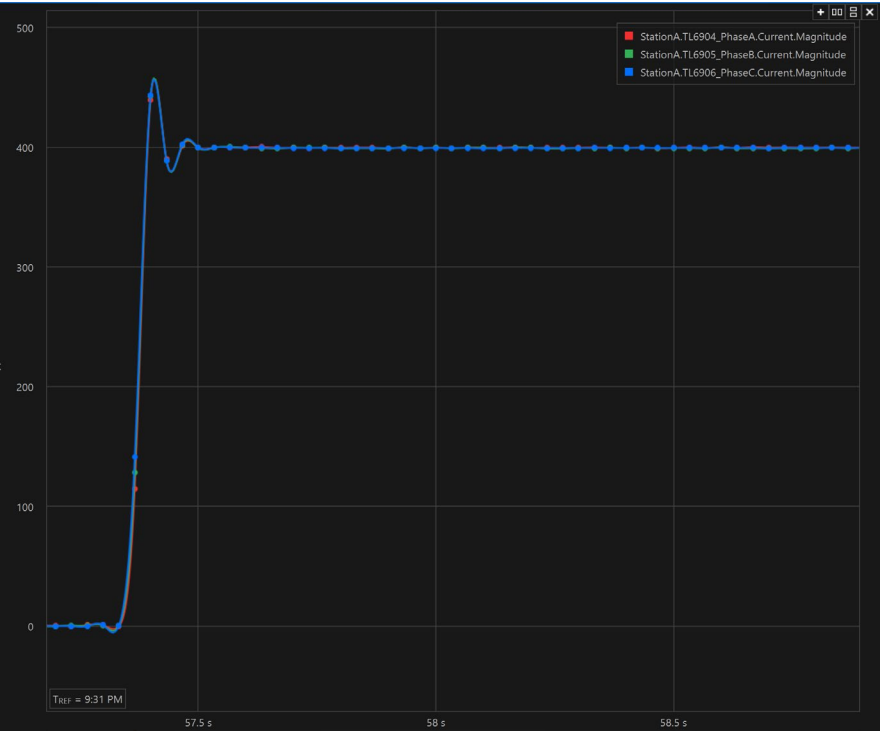
Synchrophasors on network analyzers

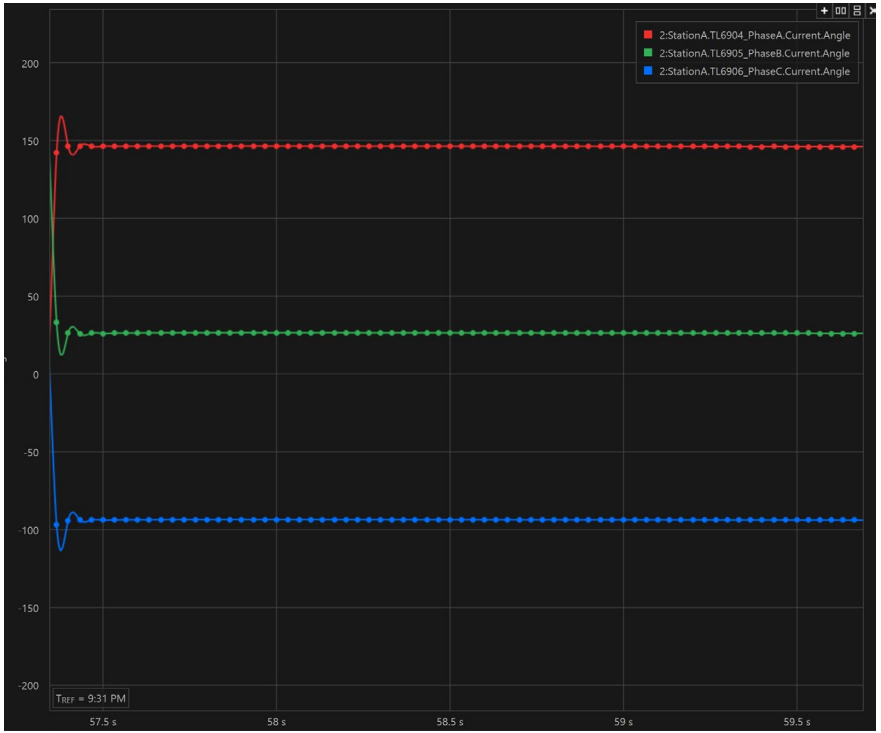
No.	Time	Source	Destination	Protocol	Length	Info
556	7.662686	169.254.3.10	169.254.3.21	SYNCHROPHASOR	102	Data Frame
558	7.700255	169.254.3.10	169.254.3.21	SYNCHROPHASOR	102	Data Frame
560	7.733522	169.254.3.10	169.254.3.21	SYNCHROPHASOR	102	Data Frame
562	7.762647	169.254.3.10	169.254.3.21	SYNCHROPHASOR	102	Data Frame

Synchrophasor monitoring tools



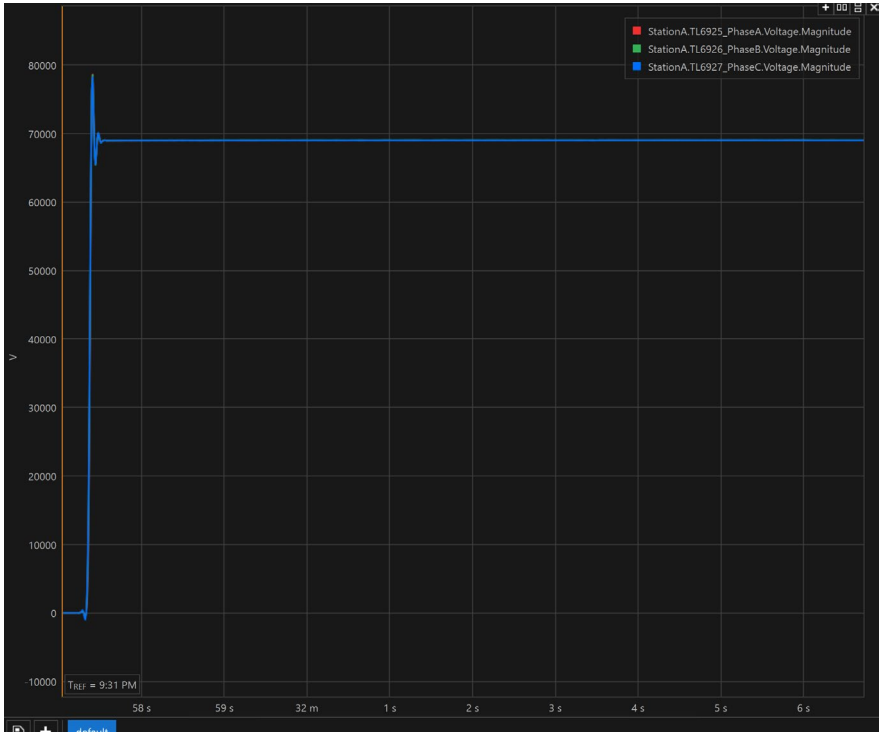
Steady State – Current Synchrophasors

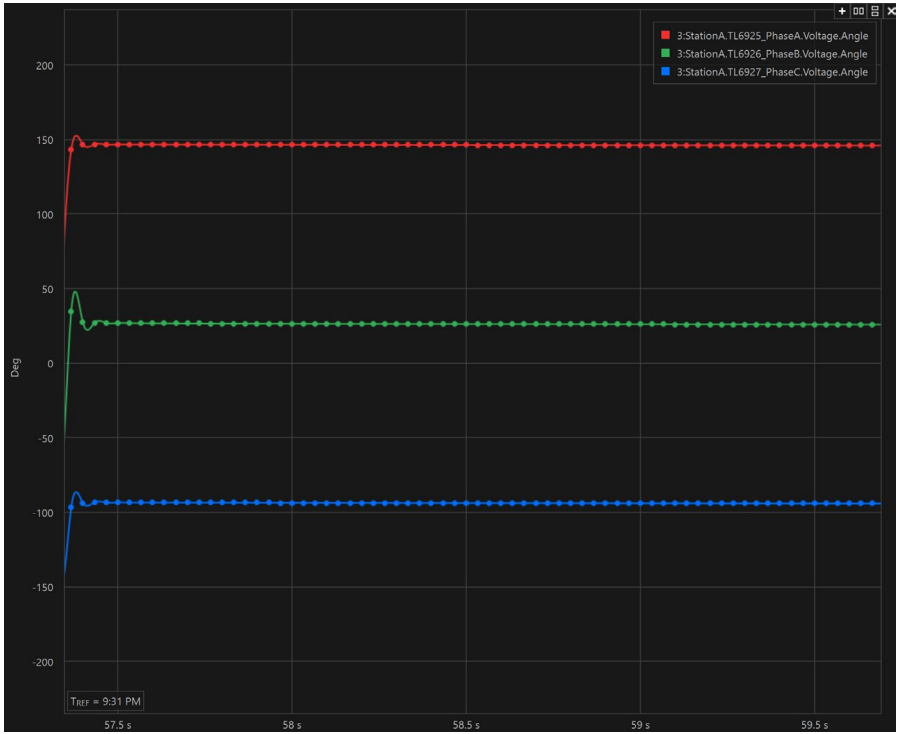




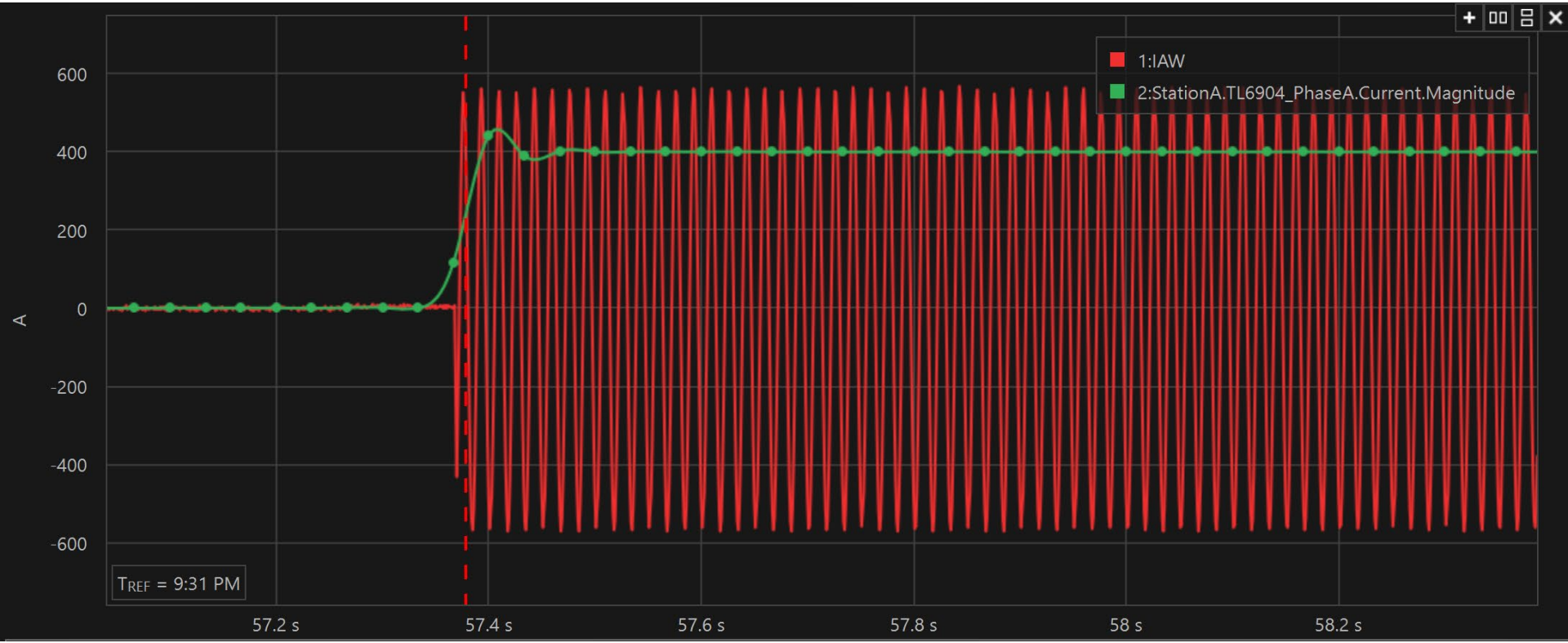
IEEE

Steady State – Voltage Synchrophasors

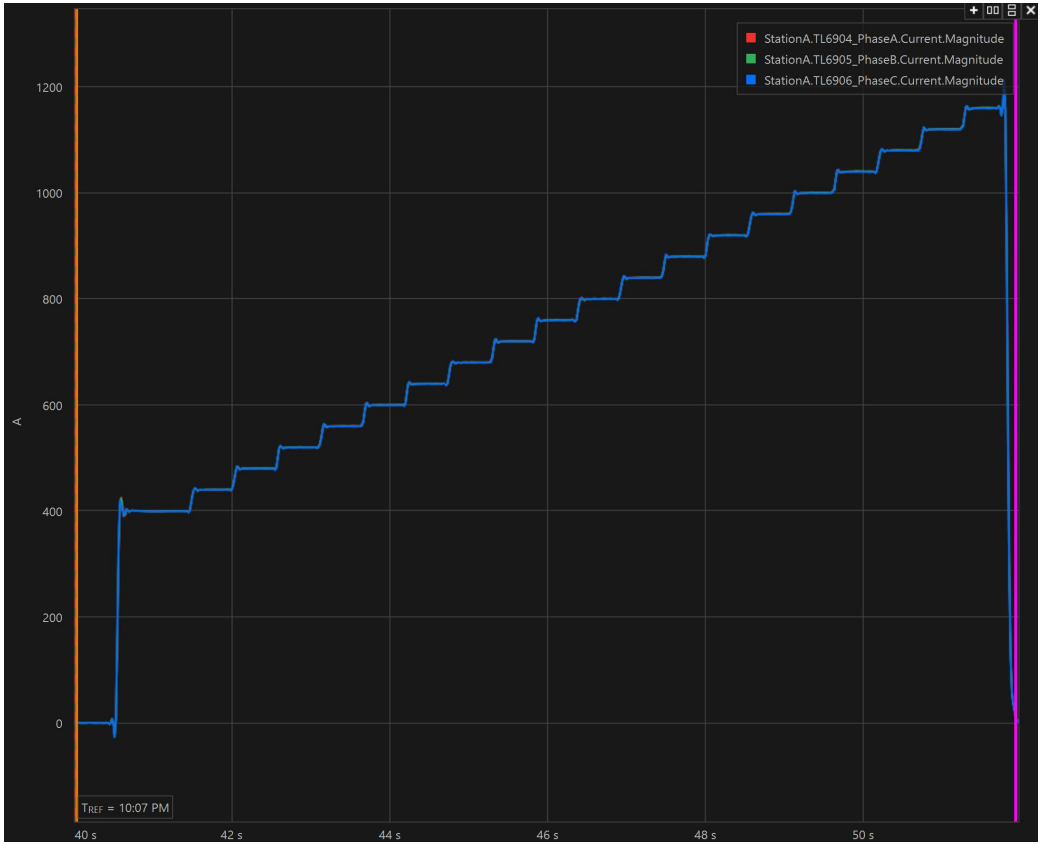




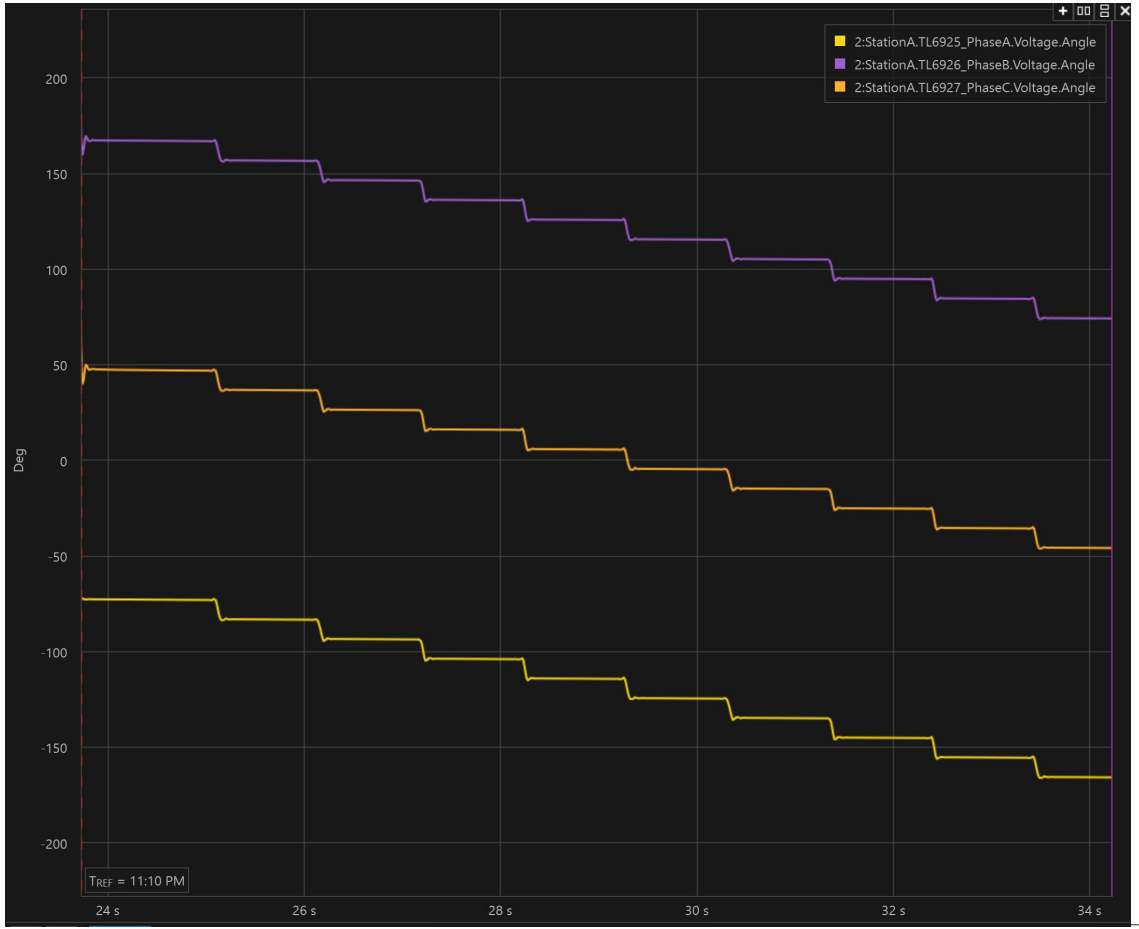
Steady State – Comparison



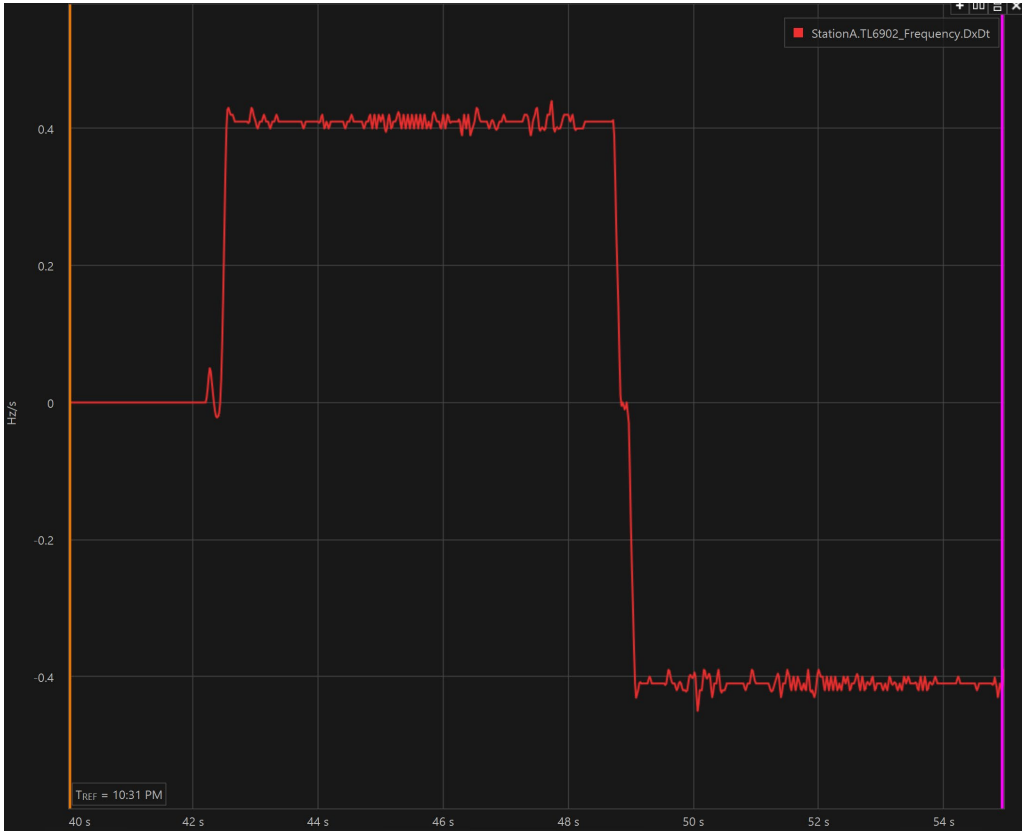
Dynamic – Phase modulation



Dynamic – Angle modulation



Dynamic – ROCOF



Dynamic – ROCOF

Summary

- Synchrophasors – time stamped data that describes the power system signals
- Phasor measurement units – applications
- 60255-118-1 IEEE/IEC standard
- Steady state and Dynamic compliance testing
- Testing considerations and test results

Questions?