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Project: TNDR 154-2015 Consultancy Services for Dynamic Modelling and Studies of Oman Power System

Report after competition of installation phase

September 2016

Client:

TRACTEBEL ENGINEERING S.A.
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Report acceptance:

TRACTEBEL ENGINEERING S.A.

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Date

Measurement performed by:

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Reported by:

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Contents

1 Introduction

This document is a report created after installation phase of a measurement campaign in project “Consultancy Services for Dynamic Modelling and Studies of Oman Power System” conducted by **TRACTEBEL Engineering S.A. (TE)**, Dubai Branch, Dubai, UAE for **Oman Electricity Transmission Company SAOC (OETC)**, Muscat, Oman.

Studio Elektronike Rijeka d.o.o. (STER), Rijeka, Croatia provided portable **phasor measurement units (STERPMU)** and web based **phasor data concentrator service (WAMSTER)** available at www.wamster.net for 5 months long measurement campaign. STERPMUs were installed in period from 29th of July to 7th of August 2016 by **United Engineering Projects Co Llc (UEP)**, Muscat, Oman with support of OETC, TE and STER. In total 20 STERPMUs were installed at 10 grid stations in different parts of Oman transmission network.

Following chapters summarize:

- information about installation of STERPMUs,
- mobile telephone communication settings,
- problems in grid stations,
- dynamics captured and event detection subsystem setup

This document elaborates findings gained during initial phase of a measuring campaign.

2 Details of PMU installations

2.1 Measurement campaign

The goal of measurement campaign is forming wide area monitoring system (WAMS) for a period of 5 months based on synchronized measurement technology (SMT) realized in phasor measurement unit (PMU).

Synchrophasor data collected by WAMS provides precise and detailed insight in dynamics of Oman transmission system. It is expected that gained knowledge will reveal unknown behavior of a system and point to roots of problems existing in transmission system.

Local disturbances captured at selected distribution nodes will be used for load modelling.

Two STERPMUs were installed in each of ten grid substations that were selected by OETC and TE, one in incomer transformer panel and one in outgoing feeder panel.

Online and historical measurements and system status is available for authorized users through enhanced WAMSTER web interface. Synchrophasors are transferred to server at default resolution of 10 synchrophasor frames per seconds (FPS) or in 100 ms resolution. In case of event detection or upon user request detailed synchrophasor stream will be recollected from STERPMUs memory at 50 FPS or 20 ms resolution for period 20 s before and 120 s after triggering of event.

2.2 Installed measurement equipment

STERPMU is portable phasor measurement unit with own GPS-based timing source, modem for communication over GPRS network, clamp on current sensors, battery backup and magnetically supported baseplate. Simple and safe installation procedure allows installation up to 4 STERPMUs in two grid stations.

Table 1 holds details about location and CT and VT ratio for each PMU installed.

Table 1: STERPMU installation details

Grid Station	DisCo	Panel	PMU ID	VT RATIO	CT RATIO	CT CLASS
Mudhairib	MZEC	Incomer 1TOA	120	33/√3 / 0.11/√3 kV	1600/1	5P15
	MZEC	1L5	121	33/√3 / 0.11/√3 kV	400/1	5P15
Rusail	MEDC	Incomer 2TOB	122	33/√3 / 0.11/√3 kV	1600/1	cl.02
	MEDC	6L5	123	33/√3 / 0.11/√3 kV	400/1	5P20
Bousher	MEDC	Incomer 4TOB	124	33/√3 / 0.11/√3 kV	1600/1	5P15
	MEDC	34L5	125	33/√3 / 0.11/√3 kV	400/1	5P20
Liwa	MJEC	Incomer 1TOA	126	33/√3 / 0.11/√3 kV	1600/1	5P15
	MJEC	9L5	141	33/√3 / 0.11/√3 kV	400/1	5P20
Sohar Main	MJEC	Incomer 1TOB	128	33 / 0.11 kV	1200/1	5P20
	MJEC	14l5	129	33/√3 / 0.11/√3 kV	400/1	
Buraimi	MJEC	Incomer 3A04A (2TOB)	130	33/√3 / 0.11/√3 kV	2000/1	5P15
	MJEC	H-LN12 (12L5)	131	33/√3 / 0.11/√3 kV	400/1	5P10
Nizwa	MZEC	132 kV NAHADA OHL (1205)	132	132/√3 / 0.11/√3 kV	800/1	
	MZEC	13L5	133	33/√3 / 0.11/√3 kV	400/1	5P10
MIS	MZEC	1TOA	134	33/√3 / 0.11/√3 kV	3200/1	5P10
	MZEC	3L5	135	33/√3 / 0.11/√3 kV	400/1	5P20
Ittin	DPC	T48	136	33/√3 / 0.11/√3 kV	2500/1	5P20
	DPC	FDR-53	137	33/√3 / 0.11/√3 kV	400/1	5P20
NPS	DPC	T46	138	33/√3 / 0.11/√3 kV	1600/1	5P20
	DPC	FDR-68	139	33/√3 / 0.11/√3 kV	400/1	5P20

Few notes on installed equipment:

- Current sensors saturate at 6.5 A or 6.5x of CT nominal values.
- There is no terminal with VT neutral potential in Sohar Main incomer panel (PM128). Protective earthing is used instead.
- Current/power orientation principle: power is positive when flowing into busbar.
- PMU132 is installed at Nizwa 132 kV OHL NAHADA instead on 33kV incomer panel according to OETC request received at site.
- Installation activities completed on Sunday, Aug 7th at 13:00 GST.

Locations of SterPMU are presented on Figure 1~~Figure 1Figure 1~~.

Archive of photos of installed equipment has been upload to project dropbox directory.

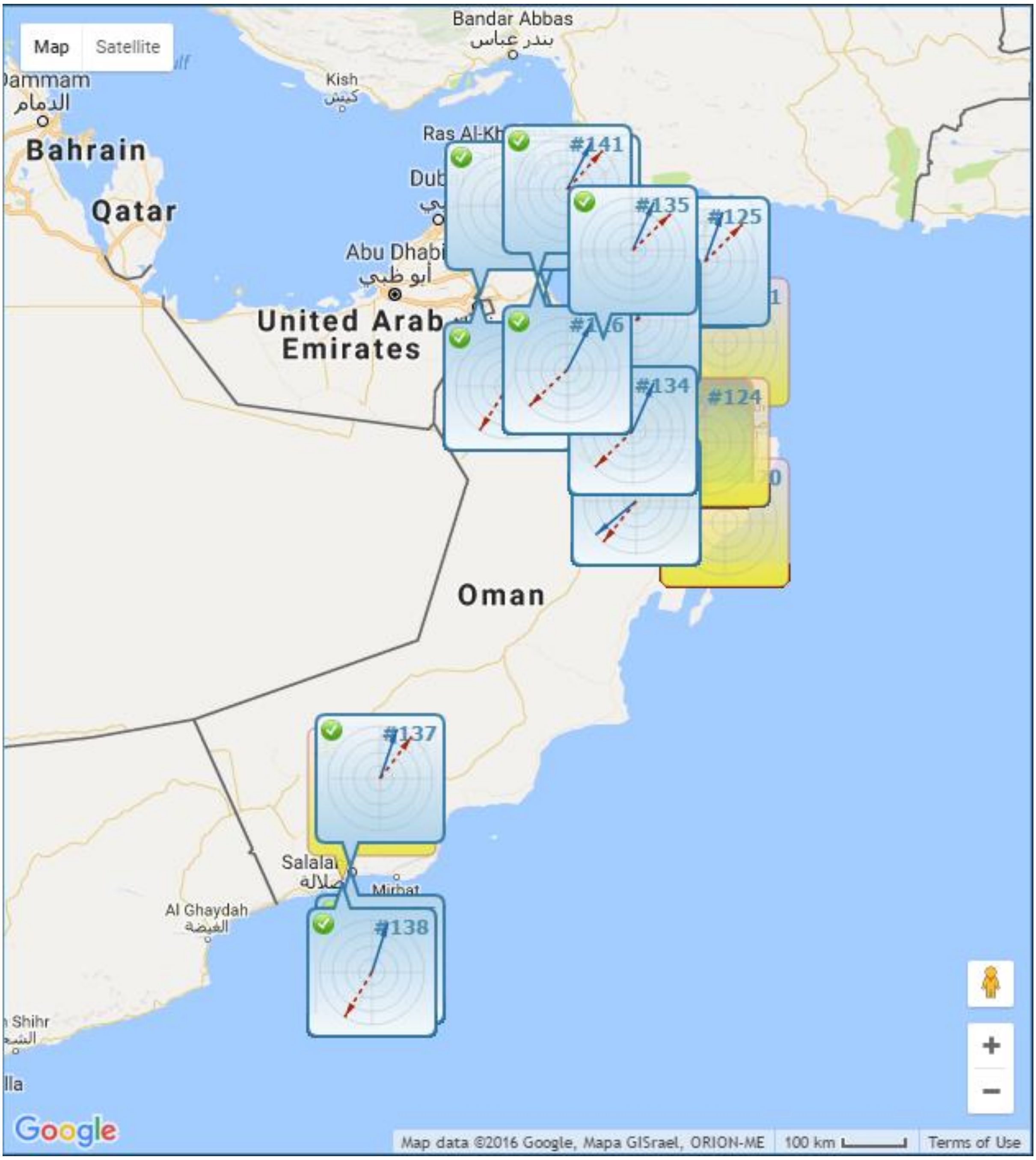

Figure 1: SterPMU locations in OETC system

3 Communication links

Mobile telephone network is used for connecting STERPMU with WAMSTER system in OETC measurement campaign. In order to avoid data loss during occasional or permanent low network throughput on some location, synchrophasor data is stored in local instrument memory and transferred to WAMSTER server in reduced resolution of 10 FPS.

Data transfer from Mudhairib grid station (PMU#120 and PMU#121) is reduced to 1 FPS because of low network coverage and frequent network unavailability. At the moment of writing of this report (20/08/2016) approximately 50% of data is transferred in default synchrophasor flow. Missing data is collected in approx. 24 hours from PMU120 and 34 hours for PMU120.

STERPMU in MIS feeder panel (PMU135) and both STERPMUs in NPS station (PMU128,139) experience frequent longer periods of network unavailability or reduced throughput. When situation improves, it takes 3 to 6 hours for data recollection.

No problem was detected at Liwa feeder after replacement of PMU127 with PMU141 and switching from Omantel to Ooredoo network on 7.8.2016.

SIM card details for each location are shown in Table 2.

Table 2: SIM cards details

PMU_ID	Installed on	Station	Panel	SIM no	Provider	Reporting rate (FPS)
120	27.7.	Mudhairib	1TOA	93970952	Oman Tel	1
121	27.7.	Mudhairib	1L5	93970493	Oman Tel	1
122	28.7.	Rusail	2TOB	93960842	Oman Tel	10
123	28.7.	Rusail	6L5	93962063	Oman Tel	10
124	28.7.	Bousher	4TOB	93963278	Oman Tel	10
125	28.7.	Bousher	34L5	93963401	Oman Tel	10
126	1.8.	Liwa	1TOA	93962794	Oman Tel	10
141	7.8.	Liwa	9L5	96423227	Ooredoo	10
128	31.7.	Sohar Main	1TOB	93960975	Oman Tel	10
129	31.7.	Sohar Main	14l5	93962048	Oman Tel	10
130	1.8.	Buraimi	3A04A (2TOB)	93968764	Oman Tel	10
131	1.8.	Buraimi	H-LN12 (12L5)	93963295	Oman Tel	10
132	2.8.	Nizwa	132 kV NAHADA OHL	93963427	Oman Tel	10
133	2.8.	Nizwa	13L5	93963453	Oman Tel	10
134	31.7.	MIS	1TOA	95198685	Ooredoo	10
135	31.7.	MIS	3L5	95201786	Ooredoo	10
136	3.8.	Ittin	T48	93962741	Oman Tel	10
137	3.8.	Ittin	FDR-53	93962836	Oman Tel	10
138	3.8.	NPS	T46	93967583	Oman Tel	10
139	3.8.	NPS	FDR-68	93958692	Oman Tel	10
127	1.8. - 7.8.	replaced		93958348	Oman Tel	10

4 Problems detected in grid stations

After installation of PMU devices, irregularities in some grid stations are detected by the usage of synchrophasor and harmonic measurements. These phenomena were detected by chance while checking the correctness of PMU connection and measurement. There may be more issues at monitored grid stations. A thoughtful examination of PMU data, that is out of the scope of contracted with STER, should be performed.

Irregularities presented in following subchapters can pinpoint problems in wiring or can be pre-failure signature of failing equipment.

4.1 Harmonic distortion in Rusail feeder voltage

As presented on Figure 2~~Figure 2Figure 2~~, total harmonic distortion (THD) of voltage measured at Rusail feeder is much higher (8%) comparing to incomer voltage (1%). The main contribution in THD is 3rd harmonic. High THD is present on all phases. In case that there is no high impedance element between incomer and feeder VTs, such high difference is not realistic.

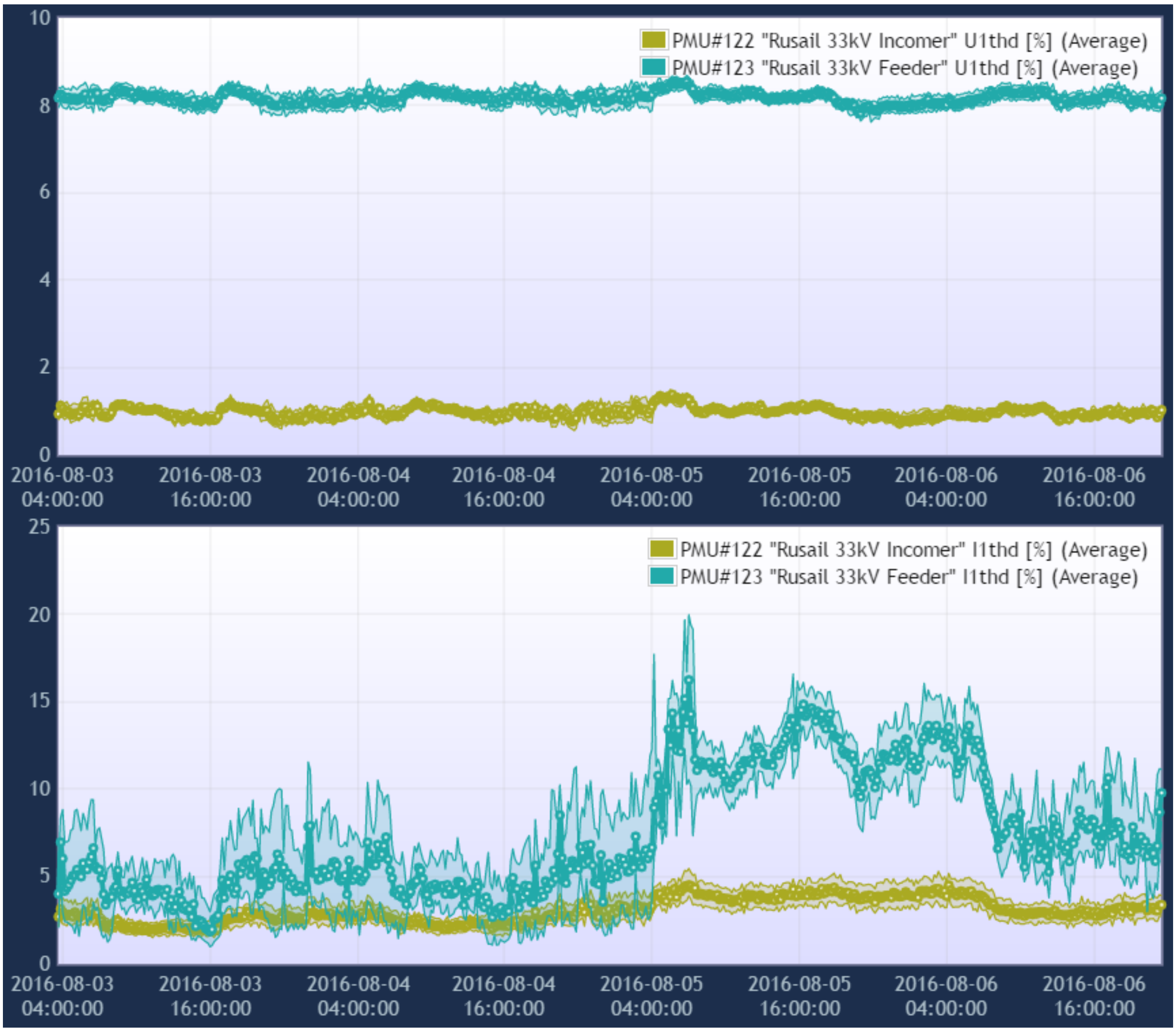

Figure 2: Total harmonic distortion in Rusail g/s

4.2 Voltage transformer problem in Buraimi sg/s

WAMS erected for OETC measurement campaign proved that there is a changing difference in voltage magnitudes and phase between phase 1 voltage measured by incomer and feeder. Figure 3Figure 3Figure 3 shows change of voltage magnitudes readings for U1 and U2. "Zero offset" function was activated to emphasize differences. Difference on phase 1 voltages was caused by increased feeder VT signal.

Phase differences between VT signals are shown at Figure 4Figure 4Figure 4. While phase 2 voltages are in phase with negligible difference, phase 1 voltage of feeder VT is lagging by 1.5°. The increase in phase 1 feeder voltage magnitude by approx. 0.5 is correlated with reducing a lag by 0.6%.

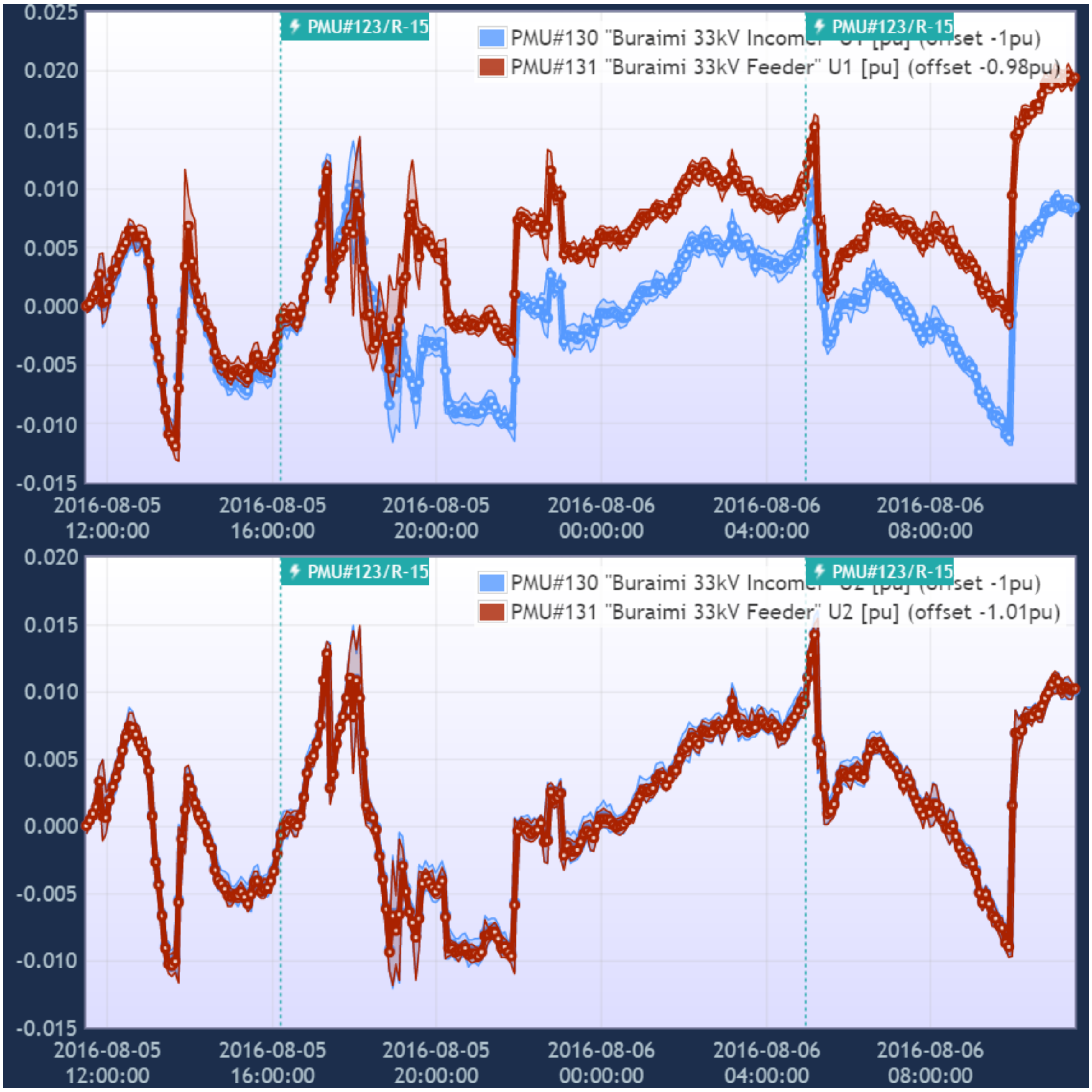

Figure 3: Phase 1 and 2 voltage magnitudes in ~~Rusail~~ Buraimi gs/s, blue – incomer, red – feeder

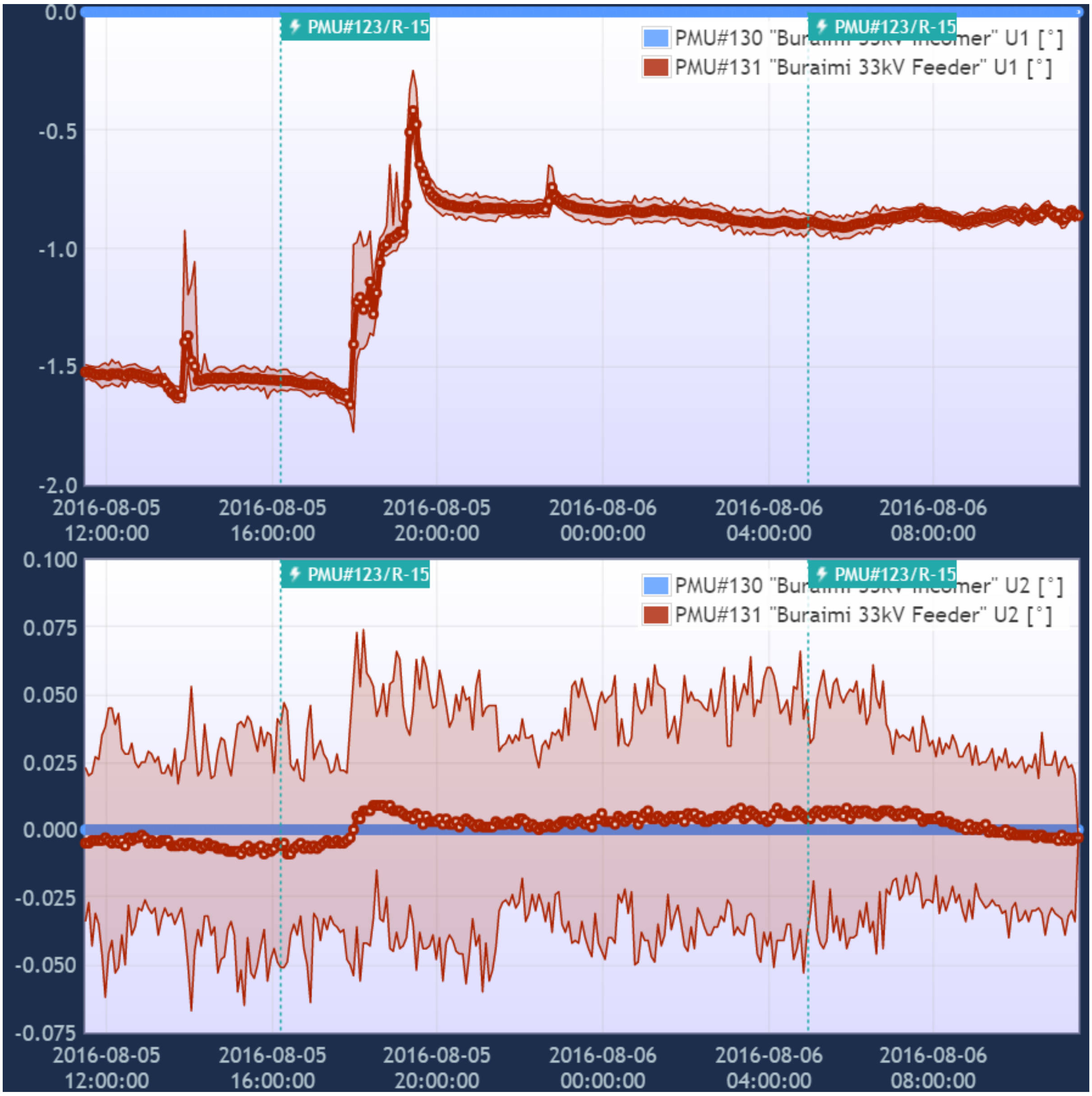

Figure 4: Phase 1 and 2 voltage angle difference in ~~Rusail~~ Buraimi gs/s, blue – incomer, red – feeder

Recorded phenomenon can be induced by problem in primary equipment, deterioration of VT or problem in secondary wiring. Further examination at site is needed to pinpoint real cause.

4.3 Inverse and zero component at Nizwa 132 kV OHL NAHADA

PMU132 installed at 132 kV OHL NAHADA in Nizwa g/s measures 2.3% of inverse and 2,3% of zero symmetrical component. At the same time readings equal 0.2% and 0.0% at 33 kV bus bar.

The cause of this unbalance is lower value measured at 132 kV at phase 2 (0.97, **0.90**, 0.98) comparing to measurements at 33 kV (0.96, 0.96, 0.96).

A further investigation is needed to determine whether it is VT problem or actual situation at 132 kV level.

4.4 Auxiliary power supply

Interruptions or dips were recorded on auxiliary power supply 230VAC voltage at:

1) Mudhairib (both PMUs): 2016-08-08 13:28:28 till 2016-08-08 13:42:01
2) Bousher (both PMUs) 11.8. 12:34:33 till 12:35:01
3) Liwa (both PMUs) 11.8. 11:14:57, duration 4 s, 11:15:03, duration 4 s.

No variation was detected at 33 kV levels at the time of aux. supply dip/interruption.

4.5 GPRS communications

Two problems were detected during installation phase of a campaign:

- low throughput of Omantel GPRS network at location of Mudhairib grid station and
- long communication downtime for PMU#127 installed at Liwa feeder.

Default reporting rate has been set to 1 FPS on both PMUs installed at Mudhairib grid station (PMU#120 and PMU#121) in order to reduce communication burden and increase visibility. This correction reduced number of undelivered frames and reduced delays in communication. However, following weeks exposed that downtimes and throughputs of Omantel network at Mudhairib g/s is insufficient to support 1FPS reporting rate without increasing number of missed frames. Consequently, some local events (dips, interrupts) could remain undetected until data processing that will be performed in TE at the end of campaign.

PMU#127 installed in Liwa grid station feeder wasn't communicating with WAMSTER server from 3rd to 7th of August 2016. On 7th of August communication was established after 4 days of downtime. PMU#127 was replaced with spare unit PMU#141 later on the same day. At the same time network provider was changed from Omantel to Ooredoo. No problem has been detected after that intervention at the particular location.

Observation during several weeks of the measurement campaign confirmed that quality and throughput of GPRS network varies with location and time. Except to before mentioned Mudhairib area, significant and frequent downtimes were experienced at MIS grid station (PMU#134 and PMU#135) and in lesser extent at NPS power station (PMU#138 and PMU#139).

STER is analyzing situation in OETC measurement campaign in order to implement a change in communication part of firmware that will accommodate adaptation to local specifics and mitigate discovered communication problems. STER strongly believes that modification of PMU firmware will help in reducing communication downtime and that overall communication performance will improve in future.

5 Event triggering settings

STER analyzed records of OETC dynamics till 15th of August. Trigger subsystem was activated on 16th of August based on triggering setting received from TE and modified according to gained insight in OETC system dynamics.

Parameters of triggering channels and thresholds are shown in Table 3~~Table 3Table 3~~.

Table 3: Event detection settings

Activation Criteria	Trigger setting
Under Voltage	< 0.9 pu
Over Voltage	> 1.1 pu
Voltage Variation Rate	Abs (Actual value – low pass_3s) > 4 %
Under Frequency	f<49.9 Hz
Over Frequency	f>50.1 Hz
Frequency Variation Rate	Abs (Actual value – low_pass_3s) > 0.05 Hz Abs(low_pas_0.3s – low_pass_3s) > 0.025 Hz
Phase Imbalance (Negative sequence voltage)	U(-) > 2% for all PMUs U(-) > 3.5% for PMU132

Note for Nizwa g/s 132kV OHL NAHADA (PMu#132): due to unbalance of voltages in 132 kV line explained in paragraph 4.3, threshold for negative symmetrical component triggering is set to 2.5%.

The performance of triggering subsystem was checked by comparison of list of events detected by WAMSTER system in period from 2016-08-07 15:00 (the end of installation) till 2016-08-15 15:00 with the event list populated manually. The comparison confirmed that event detection setting works fine and that there are just two events in list populated manually that were not detected by triggering settings. Specifics of recorded dynamics of above mention events are presented in following paragraphs without getting into deeper analysis of possible root causes.

Dynamic presented in paragraphs 0 and 5.2. reveal additional dynamics in OETC system. Such recordings are more oriented towards system problem troubleshooting. Sensitivity of triggers able to expose presented dynamic could easily increase the number of events and may blur primary focus of OETC project – load and system modelling. Because of that reason, triggers that able to capture such dynamics were not activated.

5.1 Missed event: 2016-08-09 13:48:46.300 – voltage and frequency oscillation initiated in Rusail area

Voltage and frequency oscillations were detected on 2016-08-09 13:48:46.300. Figure 5~~Figure 5Figure 5~~ presents voltage magnitudes, voltage angles and frequency variation recorded at Rusail g/s incomer (PMU#122), Bousher incomer (PMU#124), Buraimi incomer (PMU#130), Nizwa 132 kV Nahada OHL (PMU#132), Nizwa 33 kV feeder (PMU#123) and NPS incomer (PMU#138). Phase angles are presented with angle of PMU in Buraimi g/s used as an angle reference. It is clear that presented dynamics shows system response to disturbances such as generator loss or improper synchronization originated in Rusail area followed by trip and topology change 2 seconds later.

Short link to event: http://bit.ly/2bNNvaM

Original link to event:

http://www.wamster.net/users/trend/?pm=122,124,130,132,133,138&ch=upossymmag,upossymang,f&f=1470736120&t=1470736180&pu=1&refdev=130&vg=1&x

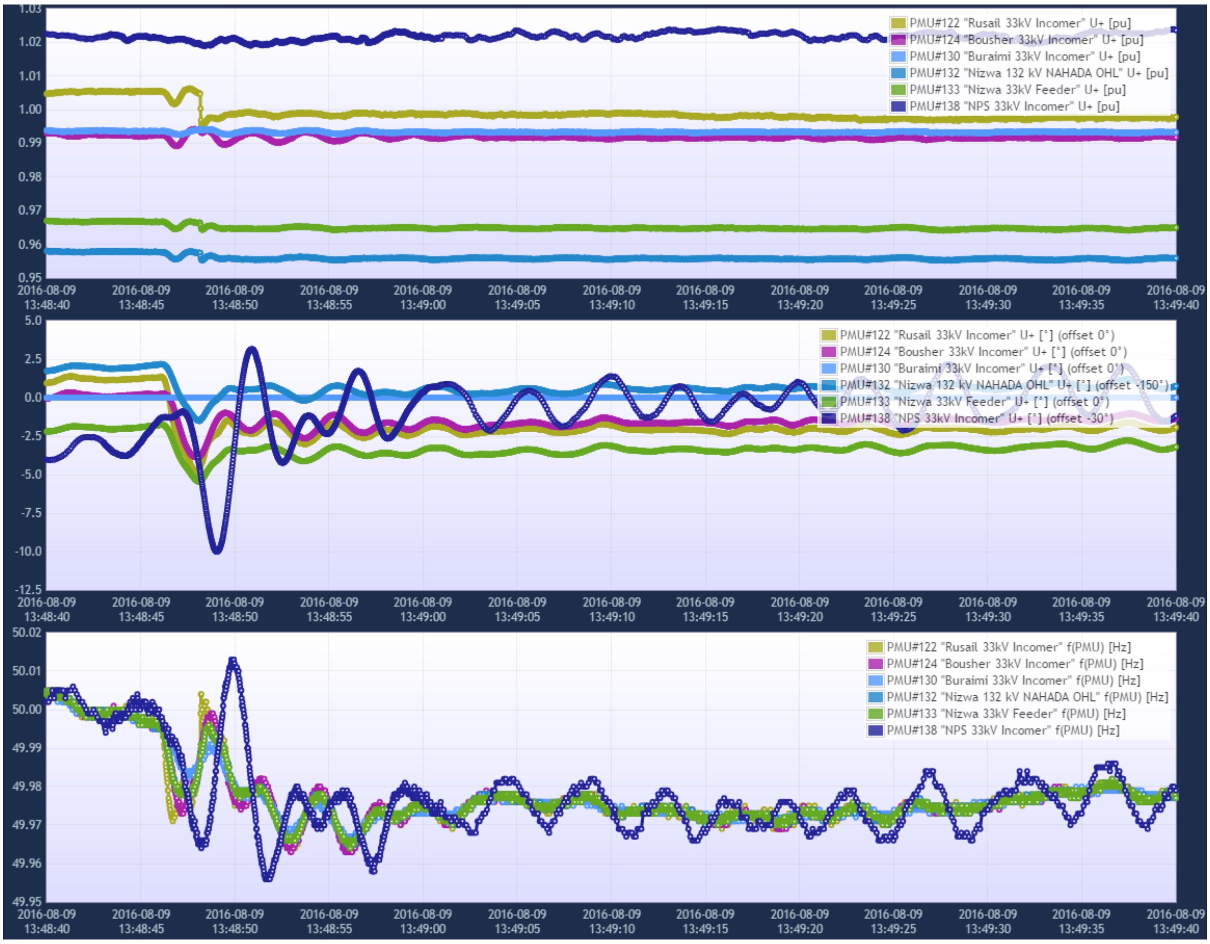

Figure 5: Voltage magnitude, voltage angle and frequency variation recorded at Rusail, Bousher, Buraimi and NPS incomers and Nizwa 132kV and 33kV systems. Referent unit for phase: PMU in Buraimi g/s

5.2 Missed event: 2016-08-12 16:15 voltage variation in Bousher area

A small variation in Bousher g/s voltage was detected 2016-08-12 16:16:00 GST. The amplitude of voltage oscillation was 0.0075 pU with duration of about 2 minutes. Recorded data revealed that variation in Bousher voltage was preceded by a misbalance in power flow. Phase angles shift presented on Figure 6 and their change shown on Figure 7 confirm that a significant change in power flow happened. The influence of power flow change was mostly noticeable in Bousher area where phase angle to Bureimi g/s changed from +5° to +0,6° in approx. 2 minutes before voltage oscillation started.

Short link to event: http://bit.ly/2cqdK60

Original link to event:

http://www.wamster.net/users/trend/?pm=120,122,124,126,128,130,132,133,134&ch=upossymmag,upossymang,f&f=1471004055&t=1471004595&pu=1&refdev=130&gps=1&zo=1&vg=1&x

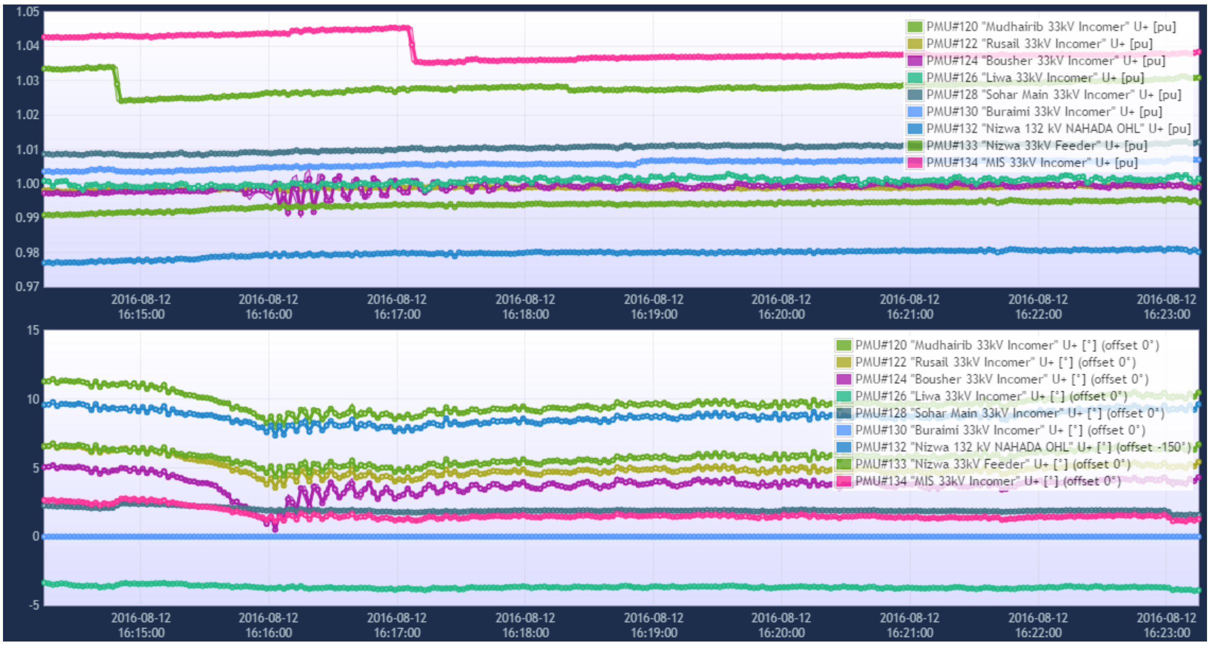

Figure 6: Voltage amplitudes and angles recorded at Mudhairib, Rusail, Bousher, Liwa, Soha Main, Buraimi, Nizwa and MIS grid stations. Angle reference: Buraimi PMU angle.

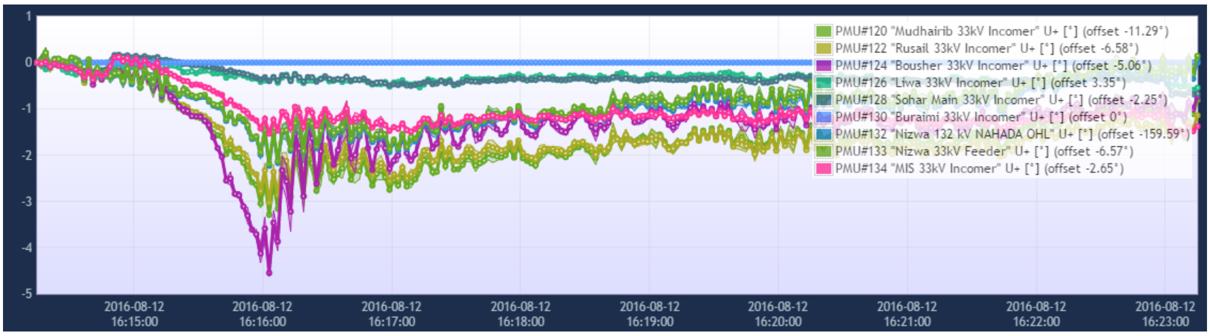

Figure 7: Phase angle change for analyzed period. Reference: angle of PMU in Buraimi g/s

6 Conclusion

The installation phase of measurement campaign was competed on 2016-08-07 15:00 when last PMU was installed in Liwa grid station.

Triggering system for event detection was set according to TE requirements and knowledge gained on OETC grid dynamics on 2016-08-16. Since that time triggering sub system has been analyzing on-line data. In order to check triggering performance and to populate event table for active part of measurement campaign, triggering subsystem parsed off-line data captured after the completion of PMU installation and stored in data base.

Selected frequency threshold fired relatively large number of events based on frequency thresholds on PMUs in Dhofar area (PMU#136…PMU#139). Captured events represent system responses to disturbances generated within PDO transmission and power flows over NIZWA-NAHADA OHL confirms that. However, too large number of events could make event list populated with rather insignificant information and analyzing of disturbance could become cumbersome. If needed, triggering system setup can be adjusted to new requirements on WAMSTER web by TE using credentials to access.

Communication over GPRS network works flawlessly except on locations Mudhairib grid station (PMU#120 and PMU#121), MIS grid station (PMU#134 and PMU#134) and NPS station (PMU#128 and PMU#139) where frequent and longer periods of network unavailability or reduced throughput were experienced. STER is working on a change of communication part of firmware to adapt to local specifics and mitigate discovered communication problems. STER strongly believes that modification of PMU firmware will help in reducing communication downtime and that overall communication performance will be improved.

Report created by: mr. sc. Dalibor Brnobić, dipl. ing. el.

Rijeka, September 4, 2016.