West Murray Zone Sub-Synchronous Oscillations

October 2022

National Electricity Market

Summary of real-time observations from August 2020 to December 2021

Important notice

Purpose

To document real-time observations and the summary of subsequent analysis of sub-synchronous oscillations identified in the West Murray Zone from August 2020 through December 2021. It has been prepared by AEMO using information available up to the date of publication, in relation to oscillations occurring up to 28 December 2021.

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All times mentioned in this report are based on Australian Eastern Standard Time (AEST), or Coordinated Universal Time (UCT) + 10, also referred to as Market Time, unless otherwise noted.

Version control

Version	Release date	Changes
1.0	4/10/2022	Initial version

Executive summary

The West Murray Zone (WMZ) of the National Electricity Market (NEM) power system spans parts of the interconnected networks in south-west New South Wales and north-west Victoria. Sub-synchronous power system oscillations in the range of 15-20 hertz (Hz)[1] lasting from a few seconds to several minutes have been observed in the WMZ on various occasions, since first identified on 20 August 2020, following a line trip in the WMZ.

The power system oscillations seem to occur both with and without any obvious network disturbances. The magnitude and duration of voltage oscillations are generally low but, in several instances, oscillations have been observed at higher magnitude[2] (range of 1% to 2.2% peak-to-peak Root-Mean-Square [RMS] at the 220 kilovolt [kV] transmission level close to Red Cliffs and Wemen) and longer duration (ranging from a few minutes to 45 minutes).

After the oscillations were first identified in August 2020, AEMO developed a bespoke tool that monitors high resolution power system quantities at Red Cliffs Terminal Station (RCTS) 220 kV and captures intervals with sub-synchronous voltage oscillations. More recently, AusNet and Powercor have installed monitors around Wemen Terminal Station (WETS) that can capture high resolution GPS synchronised data.

Sub-synchronous oscillations are characterized by power system oscillations below the fundamental frequency (50 Hz), including network voltage and current.

This document provides a summary of AEMO's analysis of real-time observations gathered in relation to five separate instances of network voltage oscillations with a magnitude of up to 2.2% peak-to-peak RMS at RCTS 220 kV.

Although the present nature of observed power system oscillations is not an immediate threat to power system security, it is important to comprehensively understand this phenomenon and its relationship with a number of power system elements, as undamped oscillations in the power system are not desirable. They have the potential to cause voltage waveform instability and create resonances, which can lead to uncontrolled tripping and damage of power system equipment. With increasing penetration of wind and solar generation within WMZ, the problems can further be exacerbated under weak grid conditions. While it has not yet been possible to establish a clear cause or causes for oscillations in WMZ, the findings to date indicate a number of potential contributing factors, and other factors that appear to have no clear correlation with the oscillations.

Key findings to date

All evidence to date points to the oscillations being contained in the area to the west of Bendigo and Darlington Point. The largest magnitude of oscillations has been observed around the Wemen area.

The oscillations were observed during an outage of the Red Cliffs to Buronga 220 kV line (OX1 line) and during periods when Murray Link DC (MLDC) was disconnected, indicating the likely source of oscillations within north-west Victoria.

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[1] The observed frequency range of 15-20 Hz is based on RMS data. Therefore, the instantaneous three-phase measurements will have oscillations in the range of 50 ± (the observed frequency in RMS plots) Hz, please see note in Appendix A1.

[2] As a reference, 7.5 Hz frequency of voltage oscillation on the Pst=1 curve from Appendix A of IEC 61000-3-7 corresponds to a 0.3% limit on % RMS peak-to-peak voltage change assuming rectangular characteristics and 900 changes/minute.

For a few instances, where a large magnitude of oscillation was observed, AEMO analysed the total reactive power (Q) and RMS voltage (V) relationship of online generating units in the region. It is difficult to draw conclusive findings from these observations alone, and it is also noted that Yatpool solar farm was not commissioned when the oscillations were identified by AEMO on 20 August 2020.

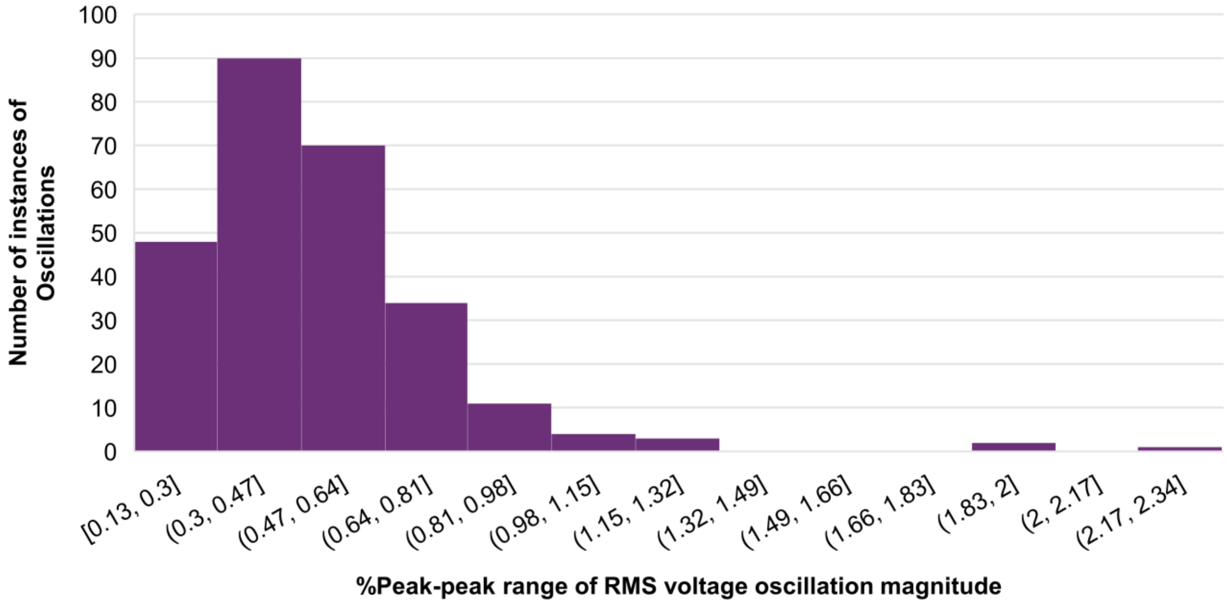
During periods when reduced numbers of inverters from solar farms were online, the oscillations were still present, but the observed magnitude was distinctly lower.

In three of the five cases studied, oscillations were observed when Wemen solar farm was either disconnected, tripped or not generating active power.

For the sub-synchronous oscillations detected on various occasions, load ramping at Wemen, Boundary Bend, Ouyen, Mildura and Merbein zone substations were analysed. However, to-date, no clear correlation has been established between the onset or presence of oscillations and the ramping of loads in the region.

A summary of oscillations observed (from August 2020 to December 2021) at RCTS 220 kV is shown in Figure 1 below.

Figure 1 Summary of oscillations observed at Red Cliffs Terminal Station 220 kV, August 2020 to December 2021



AEMO, in collaboration with AusNet and Powercor, continues to monitor and investigate the oscillations in the WMZ region. Further investigation is ongoing, including installation of additional high-speed monitoring devices across the network and desktop analysis to investigate solutions.

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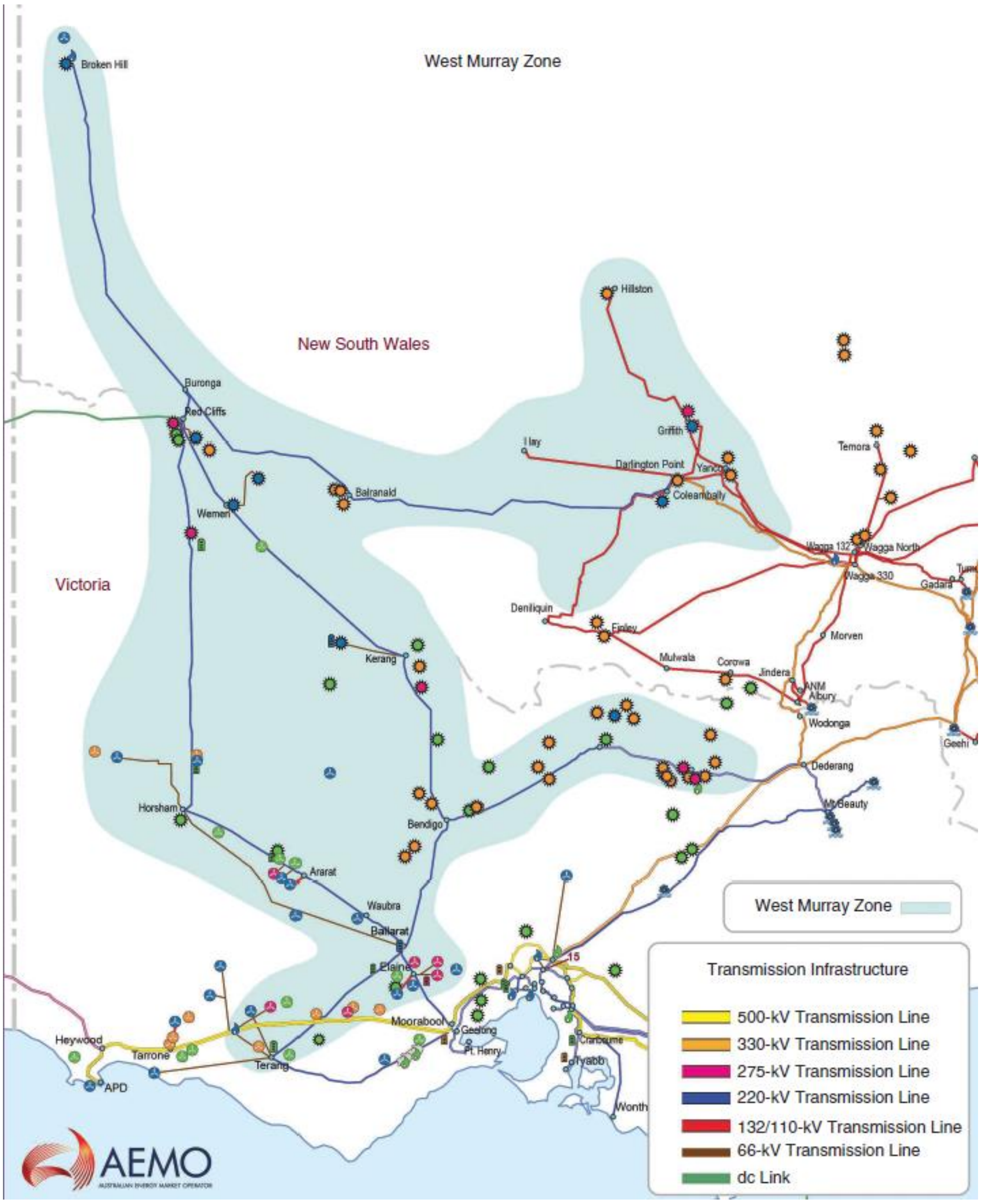
1 Introduction

The West Murray Zone (WMZ) is an area of the National Electricity Market (NEM) that encompasses the interconnected transmission and distribution networks in south-west New South Wales and north-west Victoria, as indicated in Figure 2. The region has seen unprecedented integration of renewable inverter-based resources (IBR), all using grid-following technology, in the past few years, and several more large-scale IBR connections are expected in the area. The area has been historically low in system strength, owing to low synchronous fault levels due to its remoteness from major synchronous generators in Victoria and New South Wales. These two factors – remoteness to synchronous generation coupled with high penetration of IBR – have resulted in some technical operational challenges in this region. One of these challenges, the occurrence of sub-synchronous oscillations, is the focus of this report.

Figure 2 West Murray Zone

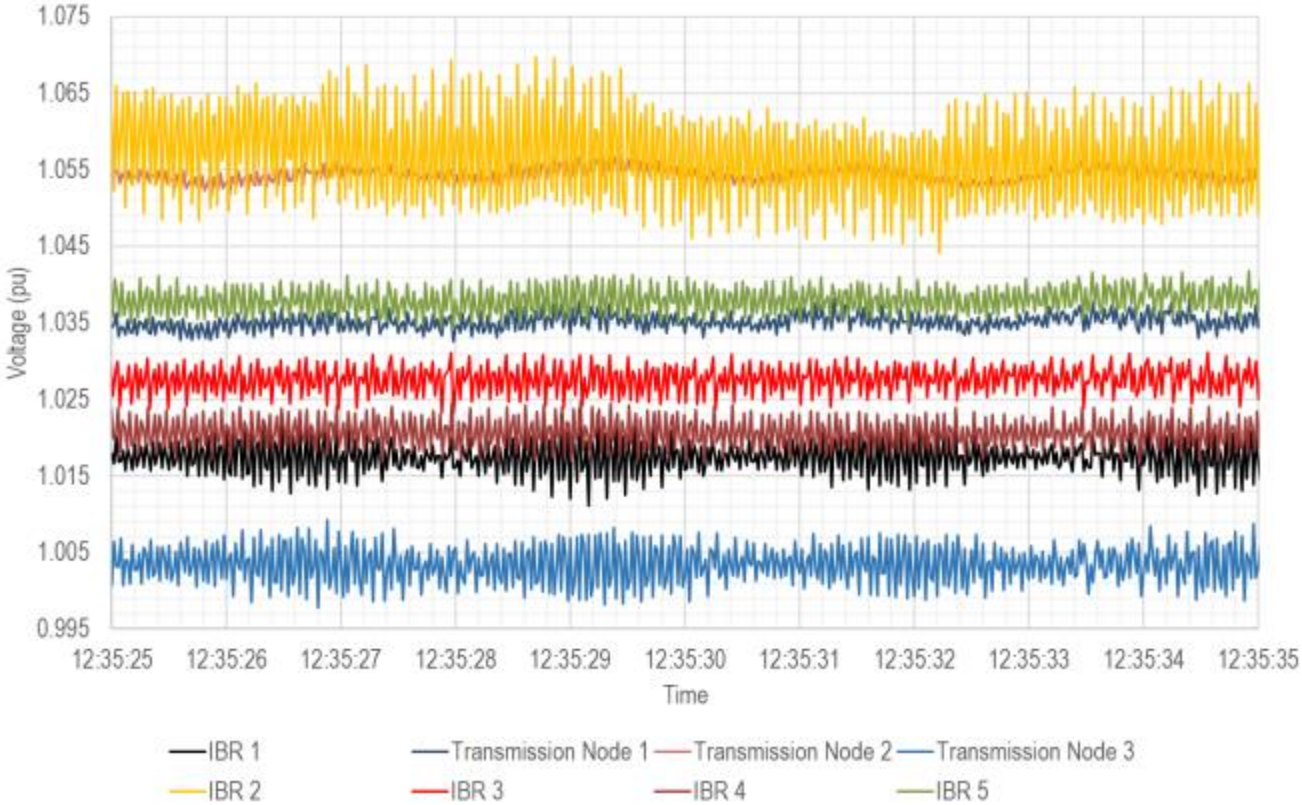


Although the present nature of these oscillations has not posed an immediate system security risk, the presence of undamped oscillations in the power system is not desirable. This can lead to uncontrolled disconnection or tripping of IBR generators due to voltage waveform instability and potentially create system resonant conditions, which could then further damage power system equipment. Moreover, as the penetration of IBR resources continues to increase in WMZ, these problems can be further exacerbated during weak grid conditions. Hence, it is necessary to identify and mitigate undamped sub-synchronous oscillations.

On 20 August 2020 at 1235 hrs, following the trip of a 220 kilovolts (kV) transmission line, sub-synchronous oscillations with a frequency of around 19 Hz were noticed for approximately 30 seconds in WMZ. AEMO conducted a review of these oscillations as a reviewable operating incident[3], publishing an incident report in March 2021.

Figure 3 shows the root mean square (RMS) voltage oscillations observed at the transmission level on 20 August 2020, including at the point of connection (PoC) of some IBR generators. The magnitude of oscillations was highest at the PoC of IBR2[4]. Also, it can be observed that the oscillation magnitude is much smaller around Transmission Nodes 1 and 2 (Bendigo and Darlington Point in Figure 3, respectively), indicating that the oscillations were likely contained to the area west of these Transmission Nodes within WMZ.

Figure 3 20 August 2020, seven seconds after a transmission line trip

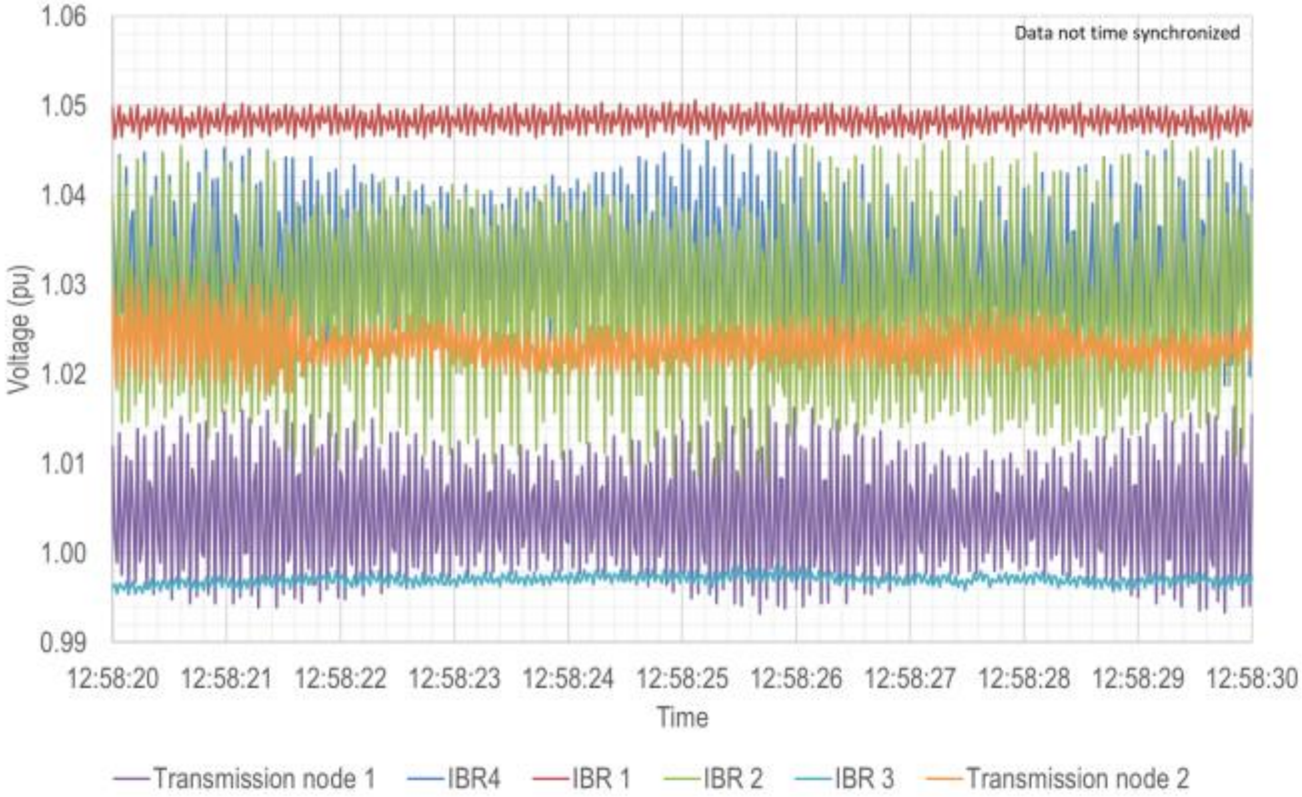


[3] Available at https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/trip-ararat-crowlands-line-20-aug-2020.pdf?la=en

[4] IBR and Transmission Node names are anonymised for the purpose of this section.

AEMO started further monitoring after this event and noticed several instances where the oscillations were observed even without any disturbances in the power system. Measurements around 1258 hrs on 2 September 2020, shown in Figure 4, indicated the presence of 19 Hz voltage oscillations in WMZ at the transmission level even without any apparent disturbances in the power system. The magnitude of oscillations at the PoC of IBR2 was the highest among all IBR locations, similar to the 20 August 2020 event. Transmission nodes 1 and 2 in Figure 4 correspond to Red Cliffs Terminal Station (RCTS) 220 kV and Limondale 220 kV, respectively.

Figure 4 2 September 2020, no apparent disturbance



2 Summary of observations

The following summarises AEMO's observations:

- The sub-synchronous oscillations seem to be intermittent and occurring both with and without any apparent disturbance in the WMZ or surrounding region. The magnitude of oscillations, as measured at RCTS 220 kV, is mostly small and usually does not exceed 1% peak-to-peak RMS, although they have been observed up to 2.2%. The frequency of oscillations is mostly around 17-19 Hz (RMS), but with some events also measuring oscillations in the slightly lower range between 15 Hz and 17 Hz (RMS).
- For three distinct events, where a large magnitude of oscillation was observed in WMZ, the magnitude of oscillations seems to be highest at Bannerton Solar Farm (SF) 66 kV PoC, followed by Wemen SF 66 kV PoC.
- The Static Var Compensators (SVCs) in the region (Horsham and Kerang SVCs) and MLDC link were unlikely to contribute in initiating or exacerbating these oscillations. As the oscillations occur even during instances when MLDC station circuit breaker was monitored as open (and transferring 0 MW). Similarly, on 11 August 2021, the oscillations continued despite the trip of RCTS – Wemen Terminal Station (WETS) – Kerang Terminal Station (KGTS) 220 kV line, and on 4 September 2020, the oscillations were observed even with Horsham SVC placed in manual mode operation.
- The role of IBR in New South Wales has also been ruled out, as the oscillations seem to occur even when the Buronga to Red Cliffs 220 kV transmission line is out of service.
- The role of loads ramping on the 66 kV network around WETS was also analysed but based on SCADA data, no correlation could be established between ramping of loads and occurrence of oscillations.
- The oscillations have therefore been identified as contained to be in the north-west of Victoria and specifically around the Red Cliffs and Wemen area, likely involving the following solar plants – Wemen SF, Bannerton SF, Karadoc SF, Yatpool SF and Kiamal SF.
- Based on instances when the response of these solar plants was analysed, the Q and V response from the solar plants were sometimes in-phase and sometimes out-of-phase. However, during the 20 August 2020 event, Yatpool SF was not commissioned and yet oscillations were observed.
- The role (if any) of nearby Gannawarra SF and Battery Energy Storage System (BESS) on the ongoing oscillations was also unlikely, as the oscillation event on 11 August 2021 resulted in oscillations continuing despite the trip of RCTS – WETS – KGTS 220 kV line.
- There were three incidents when Wemen SF was either tripped or disconnected or not in service, yet oscillations were observed.

3 Next steps

As the cause or causes of the oscillations remains unclear at the time of publication of this document, AEMO proposes following the actions and further investigation:

- AEMO is analysing the 16 November 2021 event where a large magnitude of oscillations was observed and plans to publish a reviewable operating incident report under clause 4.8.15 of the National Electricity Rules (NER) in Q4 2022.
- AEMO will work in collaboration with AusNet and Powercor on further monitoring, particularly in the distribution network around Wemen and Bannerton, to pinpoint the source of these oscillations. This would also include additional review of all major industrial loads in the area to verify the impact of load operations (and any changes in the past two years) on the performance of IBR and oscillations observed.
- AEMO, in collaboration with Powercor, is pursuing the possibility of installing additional high speed monitoring equipment on the 66 kV network, involving the PoC of Yatpool SF, Karadoc SF and other loads connected in that portion of the 66 kV network to gain better visibility.
- The voltage controller bandwidth and Q-V performance of solar plants around Red Cliffs and Wemen area – likely involving Wemen SF, Bannerton SF, Karadoc SF, Yatpool SF and Kiamal SF – should be investigated, as the IBR plants seem to present higher gain/magnitude to the oscillations observed. AEMO plans to work with network and generator owners to investigate this.
- A long-term solution could involve evolving the use of impedance analysis and monitoring techniques to identify the grid conditions for these oscillations and taking preventive measures.

A1. Note on RMS alias frequency

Most of the oscillation frequency data mentioned in this report, such as 17 Hz or 19 Hz oscillations, refer to the RMS aliased frequency as measured in the phasor variables, primarily voltage at RCTS 220 kV bus. However, the Fast Fourier Transform (FFT) of the instantaneous three-phase voltages and currents would indicate the actual frequency components to be modulated as 50 ± (the RMS frequency of 17 Hz or 19 Hz). Below is an example showing the actual frequency components (33 Hz and 67 Hz) in addition the 50 Hz fundamental, revealed by FFT analysis, for an RMS oscillation frequency of 17 Hz.

Figure 5 FFT analysis of instantaneous phase voltage at SF 66 kV PoC