Power System Operation & Control C2

System Control Room Preparedness: Today and in the Future PS1

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A tool to detect Low frequency power system oscillations in real time using PMU data

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Motivation

- Small signal instability is encountered in form of un-damped low frequency oscillations (LFO). LFO can pose a serious threat to the system stability and therefore require immediate detection and analysis. This paper presents a tool based on real-time synchrophasor data that has been successfully used in northern regional grid of India. This in-house developed tool tries to improve upon the existing OMS that has been provided by vendor in various areas such as integration of PMU data with GIS information from google maps, graphically reporting the status of PMUs, showing FFT of frequency in real-time, very small iteration window of 100ms as compared to 5 mins for existing OMS and fast detection etc.

Method/Approach

- ESPRIT method is known to perform better considering the variance in the signal and negligibal bias error due to Gaussian noise in the signal. MPM and HHT can estimate the dominant low frequency modes in the input signals and results provided by these two techniques are generally aligned with the results obtained from previously elaborated signal processing methods. It has been reported that FFT, PA and ESPRIT estimates the low frequency oscillatory modes much more accurately than the other methods. However, due to large sensitivity towards noise of PA, it gives spurious modes and computational burden associated with it is more. FFT and ESPRIT are therefore powerful and quick methods and are recommended for estimating the oscillatory low frequency modes in real-time [3]. Out of FFT and ESPRIT, FFT was found to be less computing resource intensive and therefore was selected. One more benefit of FFT is its ability to detect and differentiate multiple frequency LFOs which occur simultaneously.

Objects of investigation

- Section I : Study tours were conducted to Ostro Kutch Wind Farm (250MW) in Gujarat and Param Pujya Solar Park (100MW) in Karnataka in 2018 to identify the data that can be telemetered from the respective plants including communication approach based on available Infrastructure.
- Section II :The performance of the forecasting engine over several time blocks and seasons have been analysed and with better SCADA data availability

Programming environment

The tool has been implemented in LabVIEW programing environment. Smart grid Synchrophasor SDK (S3DK) is a real-time data mediator for PMU application development and is also an open- source LabVIEW API. The same has been used for C37.118 data parsing. The S3DK is comprised of two main parts (a) a real-time data mediator (aka DLL) that parses and handles PMU data (implemented in C++), and (b) a LabVIEW User Interface (UI). LabView user interface provides easy connection with PMUs and PDCs and also virtual instruments in LabView with different functional blocks designed to be used for interfacing the real time PMU/PDC data being received with LabView functions. The S3DK tool is compliant with IEEE C37.118.2 standard/protocol thereby making it possible to directly receive data from a synchrphasor stream from an individual PMU, or from multiple PMUs in a PDC output stream, thereby liberating one from the complexities involved synchrophasor data handling involved in dealing with the packets wrapped within the protocol.

Signal Preprocessing

A. Removal of outliers: Real-time system frequency data being received from 35 substations was used as input to the tool. It was observed that many times due to GPS synchronization errors or PMU internal errors unrealistic values of frequency were being received, if these values are not filtered out it can lead to erroneous results and false detections. A simple outliner detection and removal algorithm has been implemented which scans the incoming samples and determines whether or not the same are in a realistic range. The frequency range adopted is 48 – 52 Hz. All the samples which are outside this range are treated as erroneous and dropped.

B. Removal of blank samples and bad data: This algorithm scans incoming data for blank samples and errors which are related to bad data format such as not a number (NAN). All such samples are discarded and are not sent for further signal analysis.

C. Substitution of data in place of dropped frames : The blank frames/values so created as a result of pre-processing are filled/substituted with average of two preceding frames/values.

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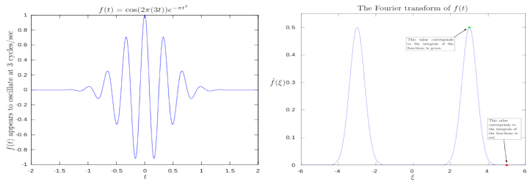
Fast Fourier transform (FFT)



The Fourier Transform is used to break a function or signal into a series which is represented by sine and cosines thereby making it possible to analyze any function as the summation of simple sinusoids. [5] FFT is a efficient and widely used signal analysis tool, and is applied to a wide variety of fields such as digital filtering, spectral analysis, acoustics, applied mechanics, modal analysis, medical imaging, instrumentation, and communications, numerical analysis, and seismography to name some.

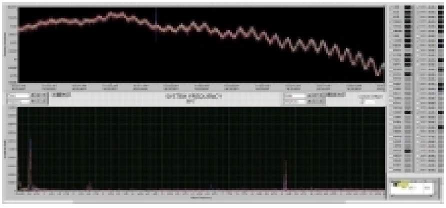
The discrete Fourier transform (abbreviated as DFT) is used to correlate discrete time sequences from discrete frequency sequence representations. DFT is represented by the following equation:

$$X_k = \sum_{i=0}^{n-1} x_i \, e^{-j2\pi ik/n} \qquad \text{for } k = 0, 1, 2, \ldots, n-1 ,$$

whe... ;, and n represents number of samples present in both discrete time as well as the discrete frequency domains. Direct implementation of the DFT, as shown in equation 2, requires approximately n2 complex operations. Whereas, computationally efficient algorithms can require as less as n log2(n) operations in total. These algorithms are known as FFTs.

Signal detrending

The output contains RMS magnitudes of different frequency components all the way from 0 Hz to 12.5 Hz (Nyquist Harmonic considering 25 Hz reporting rate). As clear from prior section LFO can be classified as Local (1 - 2 Hz) and inter area (0.1 – 1 Hz) and oscillations above 4 Hz are rarely encountered therefore in order to increase LFO detection accuracy and speed its prudent to filter out all the frequencies below 0.1 Hz and above 4 Hz spectrum.



LFO Detection Logic

- The RMS magnitudes of De-trended, filtered out frequencies (0.1-4 Hz) are continuously monitored and compared with an adjustable reference value. During an oscillation the magnitude of respective frequency components will rise sharply and if the same crosses a preset reference value a detection can be obtained. To optimize computational resources and as new data sample is available from PMU at every 40ms interval (25 Hz reporting rate) the logic is programmed to run every 40 ms. The reference value needs to be selected cautiously after through analysis of system excited modes and baselining data must be obtained from analysis of prior recorded low frequency oscillations. Four such LFO oscillations which were recorded at different parts of Indian grid were analyzed for calculating the average RMS magnitudes.

Application Graphical user interface (GUI) and LFO modes phase display

- Figure above shows the application GUI which is presented to the control room operator. The GUI updates after every 250ms and receives data from detection logic. The lower left corner has a rectangular LED indicator which turn red from green in case LFO is detected by the application. The LED turns back to green as soon as oscillation dies out. To the right of the LED indicator are two fields which show the frequency of mode with highest magnitude (LFO frequency when detection is positive) and name of substation (PMU) which is registering the same. Most of the GUI is occupied by the geographical map of northern region having 35 PMU locations been monitored by application indicated by round LED indicators. The color of the LED indicators has been linked with the phase of the individual frequency component that has been obtained from phase spectrum of FFT logic. The PMUs with more or less same color will represent coherent buses (swinging in phase) during an LFO, whereas a color difference of red and blue will indicate a phase difference of 180 degrees.

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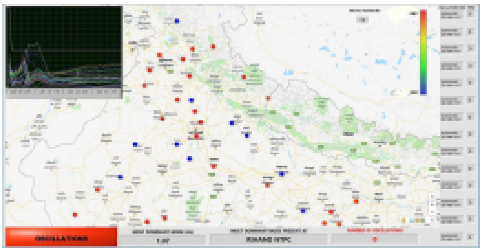
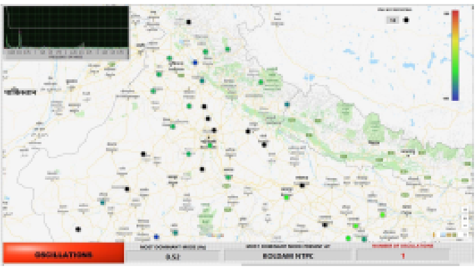
Results



- Oscillations on 18.10.2019 - The application successfully detected the oscillations and as shown in GUI the frequency of LFO was 1.07 Hz.



- Oscillations on 28.10.2019 - The application successfully detected the oscillations and as shown in GUI the frequency of LFO was 0.52 Hz.

Conclusion

The proposed method of LFO detection and analysis in real-time by using output from FFT of frequency data of PMUs after necessary pre-processing has been found to be successful in detecting LFOs that occurred in the Indian Grid on various occasions, two of which have been depicted above in results. In view of the stated benefits, successful results and ease of implementation it may be easily implemented at all SLDCs of India, as all SLDCs are already equipped with necessary synchrophasor infrastructure such as PDC etc. and are receiving PMU data on continuous basis from substations under their jurisdiction.

Further study

The present application uses FFT for LFO detection, FFT inherently is fast and less computing resource intensive but does not calculate and provide the damping factor of various modes present in system. Therefore, in future authors plan to incorporate Prony algorithm also in the application which will run in real-time every five minutes and will compute damping factor for most dominant modes of system, the detection part will be handled by FFT as in present application. The damping factor so calculated will be displayed on GUI. Further authors also plan to improve the application GUI to make it more operator friendly.