Oscillation Monitoring in Indian Power System using MATLAB

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ABSTRACT

The Indian electrical grid is one of the largest & complex networks in the world. Such complex system is subjected to stress or disturbances which manifest in the form of low frequency oscillations. Monitoring of these oscillations is necessary as they can disrupt the system if they are sustained for a longer period of time with significant magnitude. This paper presents the analysis of low frequency oscillation modes using the data from Phasor measurement units located at two extreme parts of eastern region. It reports a case study of an event that occurred in one of the Eastern regions of Indian power grid. The modes with low frequency oscillations were observed in Eastern region of the Indian grid. The Prony analysis techniques were used to identify the oscillatory modes in system during the occurrence of the event. The importance of identifying dominant mode, computation of non-dominant oscillatory modes & the role played by phasor measurement unit & their locations has been brought out in this paper.

Keyword:-*Phasor Measurement Unit (PMU), Low Frequency Oscillation (LFO), Matrix Pencil, Prony analysis*

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1. INTRODUCTION

The Indian electricity grid is one of the largest power grids in the world with an installed capacity of 223.625 GW. It consists of five regional grids i.e. NR (northern Region), ER (Eastern Region), NER (North-Eastern Region), WR (Western Region) & SR (Southern Region). Amongst these NR, ER, NER, WR operate synchronously as N-E-W grid while the SR grid is asynchronously connected to the N-E-W grid through HVDC links.

System operation has now become complex due to integration of 765 kV transmission lines, 800 MW capacity generators and 4000 MW Ultra mega power plant. The 1200 kV transmission lines and 800 kV HVDC will be introduced into the system in the future. On the track of renewable integration, each year there is a large capacity addition in wind and solar power in Indian grid which has led to skewed load generation balance as the generation from renewables is unpredictable. Furthermore intermittencyhas led to several unforeseen stability problems into the system. The decision making time by the operator of such a large grid has to be reduced with the complexity & stability problems especially small signal stability problems due to stress in the system caused by higher loading levels. Hence the need for advanced tools for monitoring and visualizingthe health of the system arises. With the recent technological advent, Phasor Measurement Units (PMUs), early warning system, intelligent electronic devices (IEDs), Wide area measurement protection and control (WAMPAC), optical fibre communication (OFC), etc. the visualization of the electrical grid has improved. Among these PMUs have come out to be a tool which has given the grid operator a real time view of the system with millisecond information. PMUs form an integral part of Wide area monitoring, protection and control (WAMPAC) systems. The Indian grid has recently installed PMUs at various locations as a part of its Unified Real Time Dynamic System Monitoring (URTDSM).

Electrical grid being dynamic in nature and faces stability challenges in day to day operation. The stability issues canbe classified on the basis of time scale into slow occurring and fast occurring phenomenon. The slow phenomenon in general, such as slow collapse of voltages that is voltage instability occurring over few minutes of time horizon can be depicted using the Conventional SCADA (supervisory control & data acquisition) system installed based on data fetched from RTUs every 10 secs. While on the other hand small signal stability cannot be observed using conventional SCADA data, thus fast measuring IEDs along with fast communication channel is required. The communication issues have been resolved with the help of OFC while the PMUs have solved the measurement issues. Now operators are able to visualize the small signal stability with the help of analysis of the PMU data from the field. Small signal instability needs to be addressed as most of the blackouts have been associated with it.

PMU provides the time synchronised measurements of voltage and current phasors along with frequency & rate of change of frequency (ROCOF) synchronised with Global Positioning System (GPS) satellite. These measurements are utilised for power system operation & for analysis of events in post-despatch scenario. These PMU measurements can also be used for Low frequency oscillation(LFO) detection.

This paper presents a study to demonstrate the application of PMU to detect LFOs in the system & actions tobe taken to damp these oscillations. The paper is organised as follows:Section II reviews the theoretical background on small signal stability, LFOs and proposed techniques for LFO mode detection Prony analysis method. Section III presents brief description of the event that occurred in Eastern region.

2. THEORETICAL BACKGROUND

2.1 POWER SYSTEM STABILITY

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

Classification of the stability of the power system:

1. Rotor angle Stability
   (a) Dynamic Stability.
   (b) Transient Stability.
2. Voltage Stability.
3. Frequency Stability i.e. Low frequency oscillations (LFOs)

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load.

Small signal instability is due to insufficient damping torque leading to **low frequency electromechanical oscillations in system**, which is oscillatory in nature.

Low frequency oscillations (LFO) are a frequent harmful phenomenon which increases the risk of instability for the power system. They limit the steady-state power transfer and change the operational system economics and security. The basic reason of low frequency oscillations is negative damping action. Low frequency oscillations can cause over current in tie lines and loss of synchronism between systems and generator sets and destroy the stability of power systems. Low frequency oscillations in the power grid can be classified into three types associated with power system events. The use of high-gain, low time constant automatic voltage regulator, or efforts to transmit bulk power over long distances may create LFOs with negative damping. The damping of these Oscillations is commonly performed with power system stabilizers.

Classification of low frequency oscillation

1. Spontaneous oscillation: Spontaneous oscillations arise when the mode damping becomes negative by a gradual change in system conditions.
2. Oscillation due to Disturbance: Outage of a line or generator under unfavourable conditions can cause oscillations by suddenly reducing damping of a mode. If the mode damping becomes negative, sustained or increasing oscillations result. If the mode becomes poorly damped, the disturbance can excite the mode to cause a transient oscillation
3. Forced Oscillation: It is due to incomplete islanding or pulsating loads.

2.2 ANALYTICAL TECHNIQUES

The purpose of this study is analysis of low frequency oscillation modes using the data from Phasor measurement units located at various regions across the country using MATLAB. The importance of identifying dominant mode, computation of non-dominant oscillatory modes & the role played by phasor measurement unit & their locations. Small signal stability problems on the power grid can cause significant electromechanical oscillations, which may cause problems if they are not properly addressed leading to grid reliability issues and potentially large-scale blackouts.

2.3 MODEL BASED TECHNIQUES

In the model based technique the nonlinear differential equations governing the system are linearized about an operating point & further the modes are obtained via Eigen value analysis. Analysis based on Eigenvalue Analysis technique is carried out through linearization of the nonlinear differential equations that represent the power system around an operating point. This approach is very comprehensive and is based on complete modelling of the Power System elements and gives all the modes in the system.

MEASUREMENT BASED:
In the measurement based techniques direct measurements from PMU estimate the linear model. Some of the popular measurement based techniques for estimating LFOs are Fast Fourier Transform (FFT), Prony analysis, Matrix Pencil, Hilbert transform, wavelet transform.

3. IMPLEMENTATION & ANALYSIS

STEP 1: AREA SELECTION

Area selected for the analysis Eastern region. Severe cases of Low frequency oscillation have been reported in the NER Grid nearby Palatana. On 09- May-15, sustained oscillation was also observed during 05:23:59.560 Hrs to 05:28:20.120 Hrs. Palatana had reported hunting of GTG I and STG I between 05:15 Hrs to 05:55 Hrs. However, no instances of hunting of generators or lines could be confirmed by other power utilities of NER. Palatana had reported that real power of GTG I & STG I varied between 218- 227 MW and between 117-123 MW respectively.

STEP 2: COLLECTION OF DATA

The oscillation on 09-May-2015 with varying magnitude, varying timeline and varying mode frequency has presented system operators with various challenges for taking their course of action to. The non-observable frequency were observed in the grid which need further analysis to find pout the root cause. To analyse the event, data from all the generators/FACTS/HVDC were collected. Data of the event on 9-may-2015 was collected from NDLC of Power Grid Corporation India Ltd. Data includes the frequency, voltage magnitude & current magnitude.
The next section is on the analysis of various data collected to find out the possible cause and the further initiative in this regard.

STEP 4: DATA ANALYSIS

Analysis of the data was done with the help of Prony analysis tool.This technique can be applied very effectively to complement the information obtained from nonlinear time domain simulations and field measurements; their value often resides in allowing for a better understanding of the dynamic characteristics of a system than that obtained from the inspection of time records alone. Of particular relevance is the computation of important modes (often lightly damped modes) and, depending on the study objectives, mode shapes and transfer functions.
Synchro-phasor data was analysed from all India PMUs. This section describes the analysis and discussion of the results. The analysis that have been done are the modal analysis on the frequency data and mode shape determination, classification of coherent group based on the mode shape, Magnitude based analysis for finding the probable root cause of the events, Mode energy index, Mode propagation path based on current of various transmission lines measured from PMUs, Online OMS data etc.

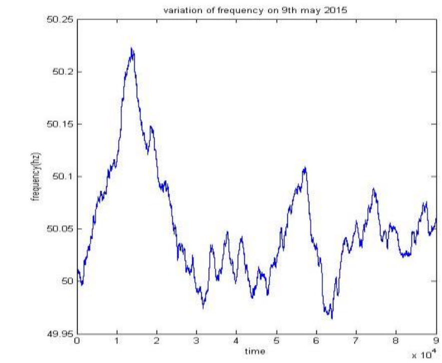

Fig. 1: MATLAB plot frequency Vs time

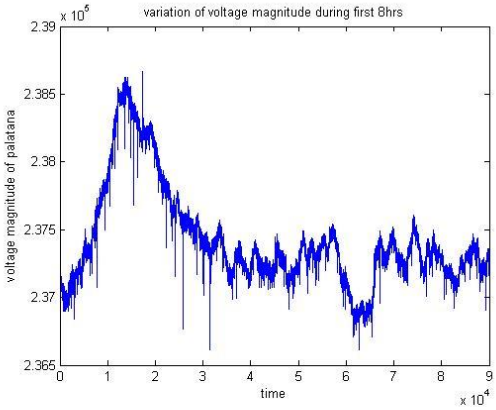

Fig. 2: Variation of voltage magnitude with data

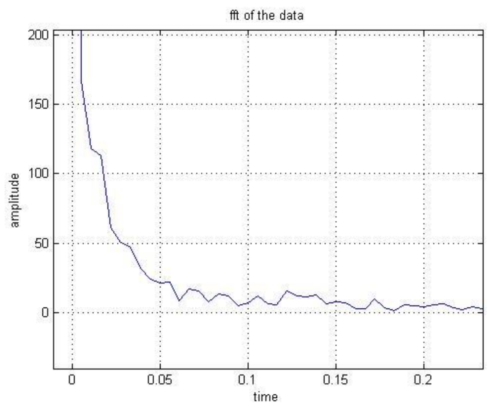

Fig. 3: FFT of the Data

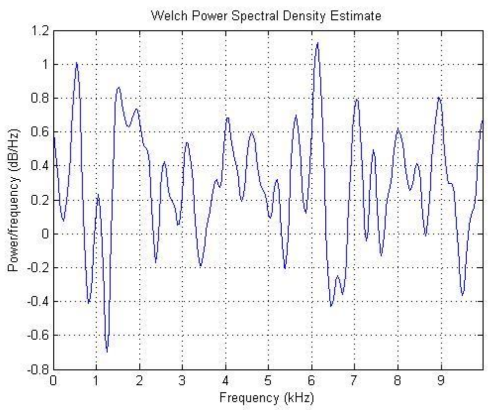

Fig. 4: Power spectral density

Analysing PMU data from WR alone provides information of the modal content in that particular region & also indicates occurrence of events as explained above. For this study PMU data from Eastern region at different locations was available during the event, which was helpful in identifying the common dominant modes between these two regions. Thesystem operator would endeavour to relieve stress in WR & ER corridors to damp this 0.75 Hz mode of oscillation.

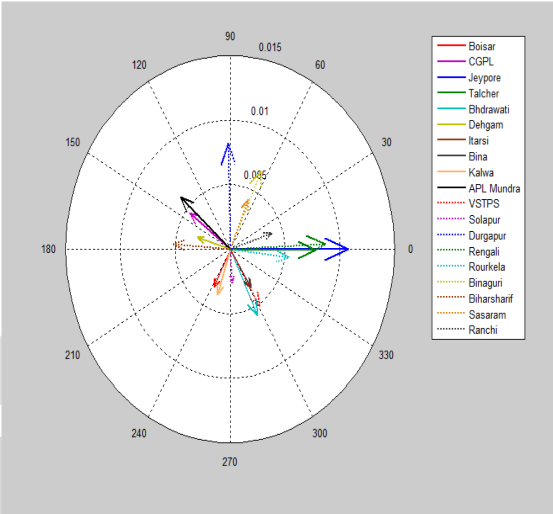

Fig. 5: Mode shape of Group 1 observed for the Frequency 0.75 HZ

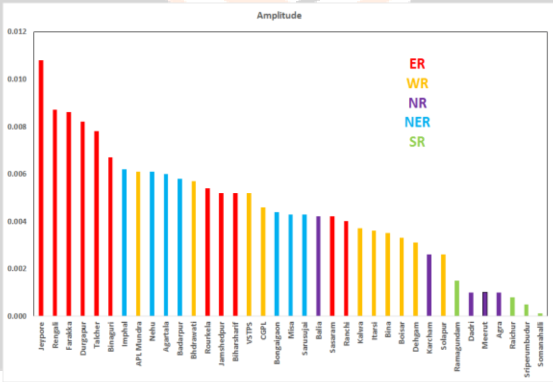

Fig. 6: Mode amplitude observed for the Frequency 0.75 Hz.

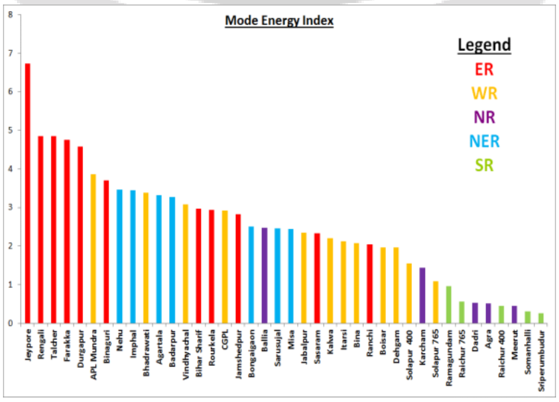

Fig. 7: Mode Energy observed for the Frequency

The importance of conducting modal analysis using different methods like Prony gets highlighted from this case study, this will enable cross-check results to increase the confidence level of the system operator. The study shows the importance of PMU placements for identification of inter-area LFOs.

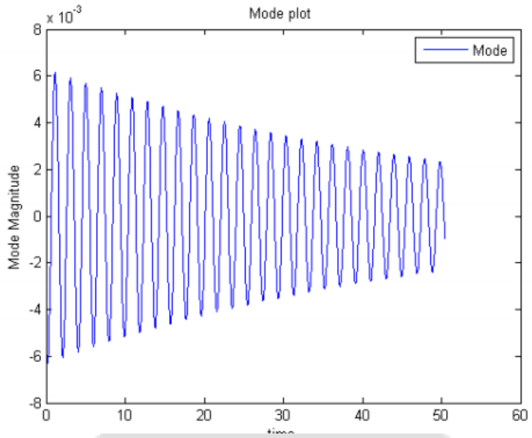

Fig. 8: 0.75 Hz mode with damping

4. CONCLUSION

This paper presented a case study in which low frequency oscillations were observed in the Eastern parts of grid under stress due to tripping of lines. This study has illustrated the sequence of occurrence of a disturbance in Eastern regions and stress in the interconnection due to loss of inter -regional lines. The data from the PMUs placed in the Eastern region at different locations have been analysed. The modes of LFOs were computed using Prony methods. The study concluded the following:

(i)The PMU placed in Palatana showed dominant mode clearly,

(ii)The Prony could identify only one non-dominant mode from the PMU at Pala. The oscillations with 0.75 Hz frequency were observed with damping less than 5% which needs to be addressed with corrective actions to relieve the stress in the system. Some of the devices in the power system to counteract negative damping include PSS in excitation system of generator & controls of FACTS devices.

The real time actions by system operator include generation re-dispatch, load shedding, circuit switching etc. to relieve the stress in the system. This study has indicated the importance of PMUs & their location towards identification of LFOs. Extensive research needs to be carried out on the optimum placement of PMUs to record the events & for analysis of LFOs in the system.

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BIOGRAPHIES

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