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'Real Time' Testing of a Decentralized PMU Data-Based Power Systems Mode Estimator

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***Abstract*—This paper presents the validation of a Phasor Measurement Unit (PMU) data-based mode estimation application in a decentralized mode estimation architecture on a 'real-time' test platform. This work is done in continuation from the the paper [1], where it was presented that decentralized mode estimation architecture could enable the application to better observe local modes whose observability could be affected by the higher observability of inter-area modes. For validation purpose, the test-system chosen is a reference grid which has a high voltage network connected to a distribution grid with distributed generation. The developed application was run in decentralized architecture where each PMU was associated with a processing unit which was running the application to estimate the modes form the time-series data. The results of the decentralized mode estimation are analyzed and compared with centralized mode estimation.**

***Index Terms*—Power System Monitoring, Phasor Measurement Unit(PMU), Mode-meter, Decentralized Mode Estimation.**

I. Introduction

Wide-Area Monitoring System (WAMS) applications have been used to acquire critical information about the network's dynamics. Modal frequency and damping ratio are useful indicators of power system stress, which usually increases with increased burden on the system. Real-time estimation of these and related parameters form time series measurements has proved to be the base for real-time power system monitoring and early warning applications. In the past, applications utilizing PMU data have been developed and implemented in WAMS for real-time monitoring [2], [3] and [4].

These applications utilize a centralized architecture where a central processor acquires data from all the connected PMUs and processes the data to estimate the modal parameters. Although [3] indicates that other architectures can aid in the performance of the mode-meter applications, no experiments (real-time, PMU in loop) or field implementation had been implemented. Authors in paper [1] have shown the benefits of decentralized architecture on synthetic PMU data. This paper validates the same architecture and application using commercial PMUs and real-time simulation of a modern distribution grid.

Remaining part of the paper is arranged in the following way: A brief introduction of the application is given in section II. Section III describes the test system and section IV presents the results. Conclusions are drawn in section V.

II. Real-Time Mode Estimator Application

The application employs measurement based system identification methods to estimate power system's modal properties. In quassi steady state, the application acquires ambient data, and runs an Auto-Regressive Moving Average (ARMA)-based, *Modified Yule Walker* method to estimate modal parameters. The application acquires PMU data using S^3DK toolkit which was developed on LabVIEW platform and presented in [5]. The source-code for the application can also be found on github [6]. The tool acts as a parser receiving signals in IEEE C37.118.2 format and converts the signals into LabVIEW datatypes.

This paper tests a decentralized architecture for mode estimation where modes are estimated by processors using single PMU data streams instead of centralized estimation where all the different PMU data streams are processed by a single processing unit. The estimated modes by local processing units could be collected and sent to higher level aggregators. This architecture aims to increase identification capability of oscillations at more local level that may be neglected by centralized architecture. For testing and validation, the mode estimator application was run in both the architectures.

III. Test System

The mode-meter application was tested to identify the modes present in a reference power grid model that includes a transmission grid along with a highly active distribution grid with distributed generation in form of wind farms and solar parks. More information about the grid can be found out in [7]. Data measurement points at HV, MV and LV levels were created to acquire PMU data. Fig. 1 shows the reference grid and selected points for PMU placement. The reference grid was simulated in real-time using a real-time

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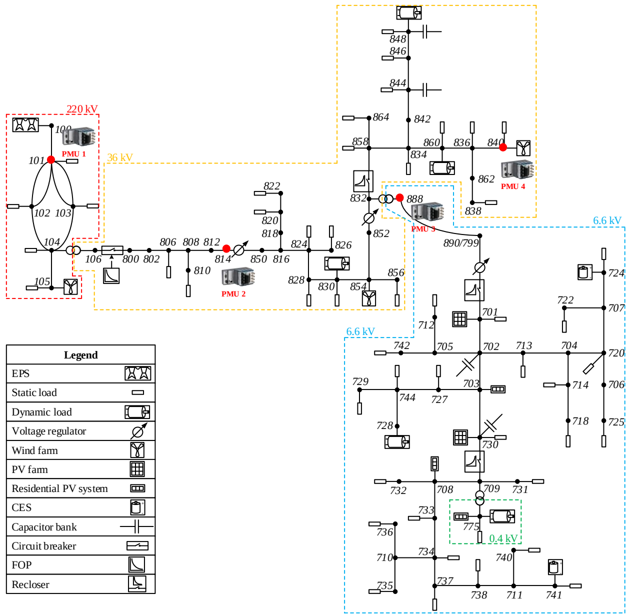

Fig. 1. Reference grid containing a transmission line connecting a synchronous generator to a modern distribution grid

TABLE I
IDENTIFIED INTER-AREA MODE AND FORCED LOCAL MODE IN THE GIRD

Mode	Frequency
Mode 1 (inter-area)	0.42 Hz
Mode 2 (forced local)	1.7 Hz

simulator. Measured PMU data from nodes 101 (HV), 814 (MV), 840(MV) and 814(LV) were stored.

To validate the results from the mode-meter application using PMU data, Fast Fourier Transform (FFT) was used to identify the inter-area and/or local modes present in the grid. The reference grid was simulated and voltage magnitude, voltage angle data were recorded in software mode. At first, FFT analysis of the data collected form the simulations of the reference grid did not show any modes present in the system. To induce some oscillations, the inertia of the synchronous generator was decreased gradually until inter-area modes were visible. The FFT analysis estimated the frequency of the oscillations to be 0.42 Hz. This inter-area oscillation was present throughout the grid. In the next step, the simulation was run in real-time and data was acquired and stored using four PMUs. The FFT analysis of the stored PMU data confirmed the presence of an inter-area mode of frequency 0.42 Hz.

To investigate the advantage of decentralized mode-estimation in identifying local oscillations, a localized forced oscillation was created by sinusoidal load variation at node 799 in the LV section with a frequency of 1.7 Hz. Both modes are shown in After this, mode-meter application was tested in real-time using data from the PMUs. Section IV presents the results.

IV. Results

This section presents and validates the results obtained by the mode-meter application running in real-time. Results obtained from both centralized and decentralized architecture are presented for comparison and verification. Voltage magnitude and voltage angle difference are used as input signals to the application. Estimates were calculated on a moving window of 6000 samples and ten minutes of time series data. Each test was run for about one hour. The estimated results were stored in an excel file for further analysis. Probability Distribution Function (PDF) plots were plotted for frequency and damping ratio estimates.

A. Voltage Magnitude

Positive sequence voltage phasor magnitudes acquired form the four PMUs were used as input signals for the mode-meter application. PDF plots based on the estimates were obtained to analyze the results. The summary of results for centralized architecture in terms of PDF plots is presented in Fig. 2. The PDF plots suggest high density of estimates around 0.42 Hz mode whihc is the inter-area mode found out using FFT analysis. The damping ratio detected ranges from 0% to 5% range. The forced oscillation is detected although the pdf plot suggests that the density of estimates around the 1.7 Hz forced oscillation is less.

The next test case demonstrates the results from the decentralized mode estimation which tries to improve the identification ability of local forced oscillation (mode 2). Fig. 3 presents the PDF plots based on the estimates obtained in decentralized architecture. The estimates taken for this plot is only from PMU 4 and node 799 where sinusoidal load variation was taking place. The plot suggest high density of estimates around frequency 0.41 Hz and also around the frequency of 1.7 Hz. The damping ratio of the forced oscillation is estimated to be 0%.

On comparison of the plots it is clear that the local oscillation is better identified by the local decentralized architecture in case of voltage magnitude signals.

B. Voltage Angle Difference

In this test, difference between voltage the angles measured at the four PMU nodes was used as input to the mode-meter application. The PDF plot based on centralized estimation is presented in Fig. 4. Similar plot for decentralized estimation using the data from PMU at node 799 is presented in Fig. 5.

Both the PDF plots indicate the success of mode-meter application in estimating the inter-area oscillation at 0.42 HZ as well as the local forced oscillation at 1.7 Hz.

V. Conclusion

A mode-meter application was tested and validated in real-time using PMU data stream. The application was run in two different modes: centralized and decentralized estimation modes. Voltage magnitude and difference in voltage angles were tested as inputs to both the architectures. It was shown

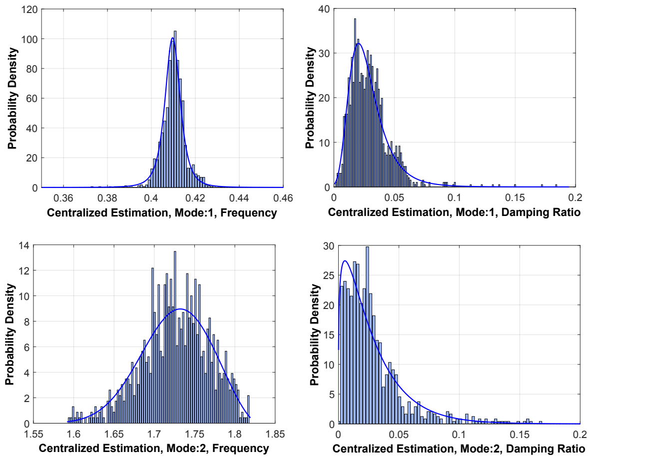

Fig. 2. Estimates from centralized estimation with voltage magnitude signals; TOP: PDF of Mode 1 frequency (left), PDF of Mode 1 damping ratio (right); BOTTOM: PDF of Mode 2 frequency (left), PDF of Mode 2 damping ratio (right).

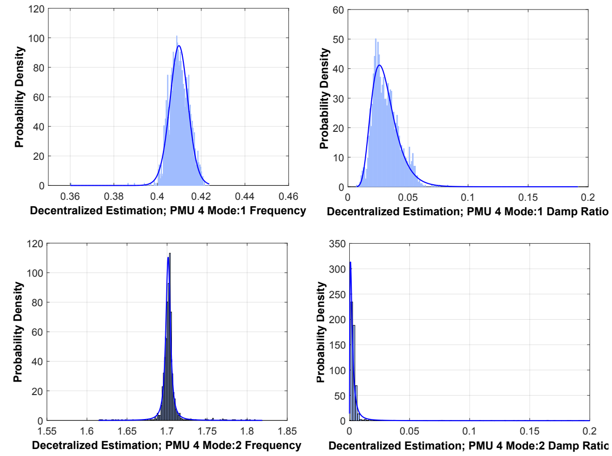

Fig. 3. Estimates from decentralized estimation with voltage magnitude signals; TOP: PDF of Mode 1 frequency (left), PDF of Mode 1 damping ratio (right); BOTTOM: PDF of Mode 2 frequency (left), PDF of Mode 2 damping ratio (right).

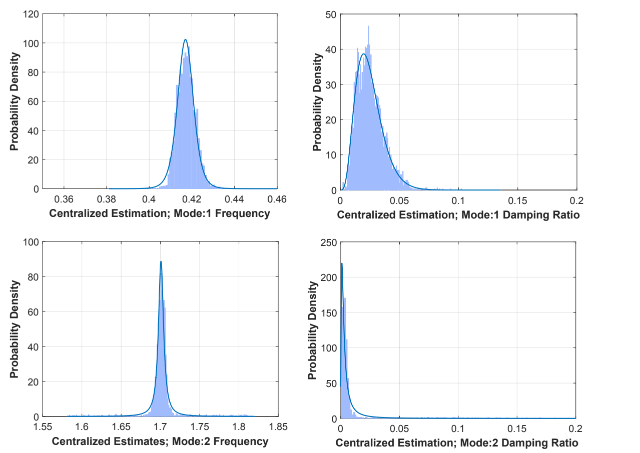

Fig. 4. Estimates from centralized estimation with difference in angles signals; TOP: PDF of Mode 1 frequency (left), PDF of Mode 1 damping ratio (right); BOTTOM: PDF of Mode 2 frequency (left), PDF of Mode 2 damping ratio (right).

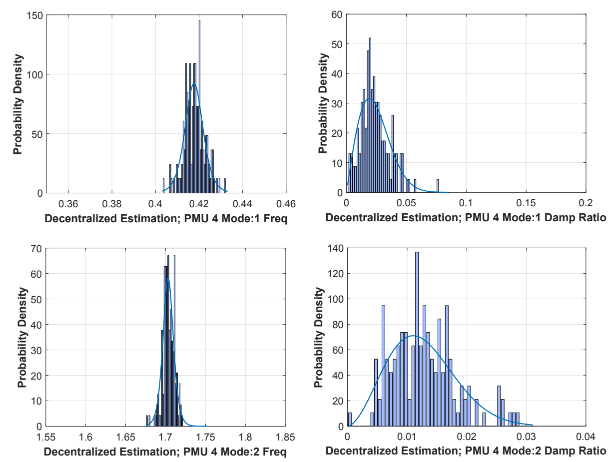

Fig. 5. Estimates from decentralized estimation with difference in angles signals; TOP: PDF of Mode 1 frequency (left), PDF of Mode 1 damping ratio (right); BOTTOM: PDF of Mode 2 frequency (left), PDF of Mode 2 damping ratio (right).

that the application was able to detect the major inter-area oscillations in both the architecture and for both the type of input signals. It was found out that in case of voltage magnitude signals, the decentralized architecture provides better estimates for the localized oscillations. Difference in voltage angles when used as input helped identify the local modes even in centralized architecture.

The results of the tests will be presented in more statistical details in the full paper.

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