A Practical Approach to Inertia Assessment: Analyzing New York's Grid Response to Real Events

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***Abstract*—The non-uniform distribution of inverter-based resources (IBRs) such as solar and wind energy leads to the formation of weakly coupled regions within the broader interconnection. This highlights the urgency of studying regional dynamics. This paper proposes a practical framework for estimating inertia using actual event measurements from the New York (NY) region. The regional frequency is determined using measurement data from frequency disturbance recorders (FDRs) deployed across NY. The rate-of-change of frequency (RoCoF) is estimated using a hybrid methodology that combines the benefits of both moving and non-moving window techniques. By utilizing the power mismatch value and the estimated RoCoF, various inertia metrics such as regional RoCoF, inertia arrival time, and inertia percentage relative to the interconnection inertia are calculated. This assessment of inertia using real event data reveals the true behavior of the grid under stress. The results indicate that as the generation mix in NY evolves with the rise of IBRs, both the RoCoF levels and the regional inertia undergo significant changes.**

***Index Terms*—Regional inertia, rate-of-change of frequency, New York**

I. Introduction

The increasing growth of inverter-based resources (IBRs) has led to a decrease in the total rotational energy from the system. In addition, the deployment of these IBRs is not uniform throughout the interconnection system. This results in the creation of small regions with low coupling with the larger electrical network (interconnection). Furthermore, this leads to reduced rate-of-change of frequency (RoCoF) levels, frequency nadir, and inertia.

Due to the reduced inertia in a region, whenever there is a fluctuation in the frequency due to some power mismatch between the generation and load, the local RoCoF might exceed the designed levels of equipments. This can lead to a cascaded generation tripping event and possible blackout, such as [1], [2]. The blackout might start from a small region to a larger interconnection network. This highlights the need for the regional inertia assessment amidst the rise of renewable energy integration for situational awareness and future planning.

For the estimation of inertia, we can either employ a model-based or a measurement-based approach. The model-based approach uses generator dispatch data and adds the inertia of the generators that are supplying power of at least 5 MW to find the total inertia [3]. Although it is very simple in execution, the major drawback of this method is not including the contribution from the load and renewable. The measurement-based method leverages the data measured by Phasor Measurement Units (PMUs). The collected data can be divided into probing signals, normal data, or event data. The normal data approach utilizes the ambient load fluctuations that happen in the system. The limitation of this method is the difficulty in a noisy data scenario, which leads to unreliable results. The probing signal approach uses an additional device [4] to inject probing signals into the system. The disadvantage of this method is the requirement of setting up a probing device, which makes the investment cost high. Other data-driven approaches, such as the use of machine learning models [5], exist; however, such approaches need a large historical dataset to train on, and they only serve as a black box model.

This paper uses an event-based measurement approach for estimating the inertia of the New York (NY) region. The event data, such as the frequency and power mismatch values during a disturbance, are used in this method. Since real events are used, they help to reflect the actual dynamics of the system during stress conditions. The inertia estimated during this condition serves to be a more accurate estimate. Unlike the model-based methods, the event-based approach helps in including contributions from all the components connected to the system that includes conventional generators, loads, and the IBRs. This practical approach aids in identifying subtle relationships within the system that are not adequately represented by theoretical models. By focusing on real-world interactions, it enhances our understanding of these dynamics.

The remainder of the paper is arranged as follows: Section

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II describes the background of the methodology; Section III explains the measurement of the frequency data and the regional dynamcis; Section IV outlines the methodology for the employed inertia assessment; and Section V presents various inertia metric results and discussion. The paper concludes by summarizing important insights from the study and the future work.

II. Methodology Background

Inertial energy refers to the kinetic energy from the rotating mass that opposes the change in the rotational speed. Whenever there is a deviation of power between load and generation, there is a power mismatch that causes the frequency of the system to change. The swing equation explains such dynamics, which can be expressed as [6], [7]:

$$\frac{df}{dt} = \frac{P_m - P_e}{2HS} f_s \tag{1}$$

where df/dt is the RoCoF, f_s represents the synchronous frequency, P_m is the mechanical power, P_e is the electrical power, H is the inertia constant, and S is the system capacity.

For an electrical region, the swing equation can be written as:

$$\frac{df_{rg}}{dt} = \frac{P_m - P_e}{2H_{rg}S_{rg}} f_s = \frac{\Delta P}{2H_{rg}S_{rg}} f_s \tag{2}$$

where the power mismatch is ΔP, the regional frequency is represented by f_{rg}, H_{rg} is the region's inertia, and S_{rg} represents the region capacity. f_{rg} can be estimated by the weighted average of the frequencies from different areas of the region as [8]:

$$f_{rg} = \frac{\sum_i^n w_i f_i}{\sum_i^n w_i} \tag{3}$$

The weight w_i represents the contribution of inertia from each area in the region. However, for simplification, w_i can be assumed to be one for all areas.

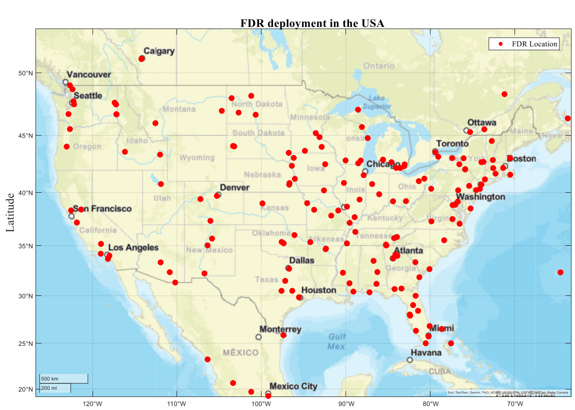

Fig. 1. FDR deployment across the US.

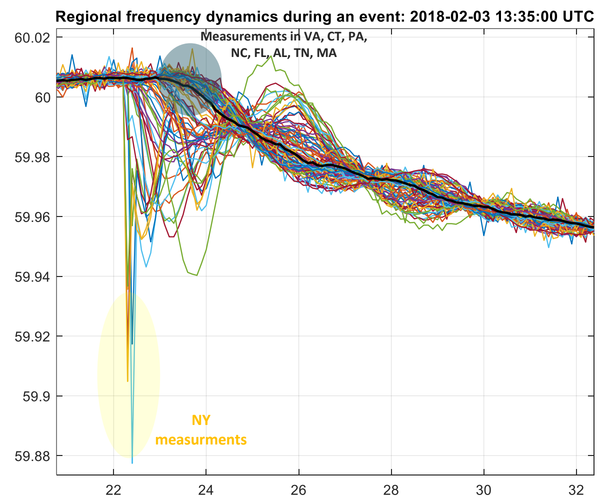

Fig. 2. Regional frequency dynamics during an event.

III. Data Measurement & Regional Dynamics

The Frequency Monitoring Network (FNET/GridEye) as depicted in Fig.1, have more than 300 frequency disturbance recorders (FDRs) distributed across the US. This serves as the major data source for the study. These FDR units collect the frequency, voltage, and phase angle from different parts of the US. The data servers are located at the University of Tennessee Knoxville (UTK) and Oak Ridge National Laboratory (ORNL) [9], [10]. This study utilizes two kinds of data: frequency data from the FNET network and the power mismatch data from the NERC (North American Electric Reliability Corporation).

When an event happens in a region, frequency swings around the central frequency of the system is observed [11]. If the coupling of the region to the larger interconnection is weak, then the swings can get substantial. In parts close to the event location, FDRs measure a quicker and sharper frequency decline as compared to those in areas far from the event location. For instance, a regional frequency response during an event is illustrated in Fig. 2. The measurements in NY indicate a quicker and sharper frequency drop before frequencies from other parts start dropping. The areas like VA, CT, PA, NC, FL, AL, TN, MA, etc., appear more closely integrated with the larger system. However, NY seems to be slightly detached from the rest of the system. The measurements from NY's FDRs are coherent and represent a cluster of frequency. This is because the inertial support from different parts of the interconnection take a few milliseconds to reach the event source location. This highlights the importance of studying regional dynamics' during an event.

IV. Inertia Assessment

The proposed framework for the assessment of the inertia of a region is illustrated in Fig. 3. Once the measurement data is collected, the FDRs present in the region are utilized to estimate the central frequency, which represents the regional frequency. The regional frequency is calculated according to

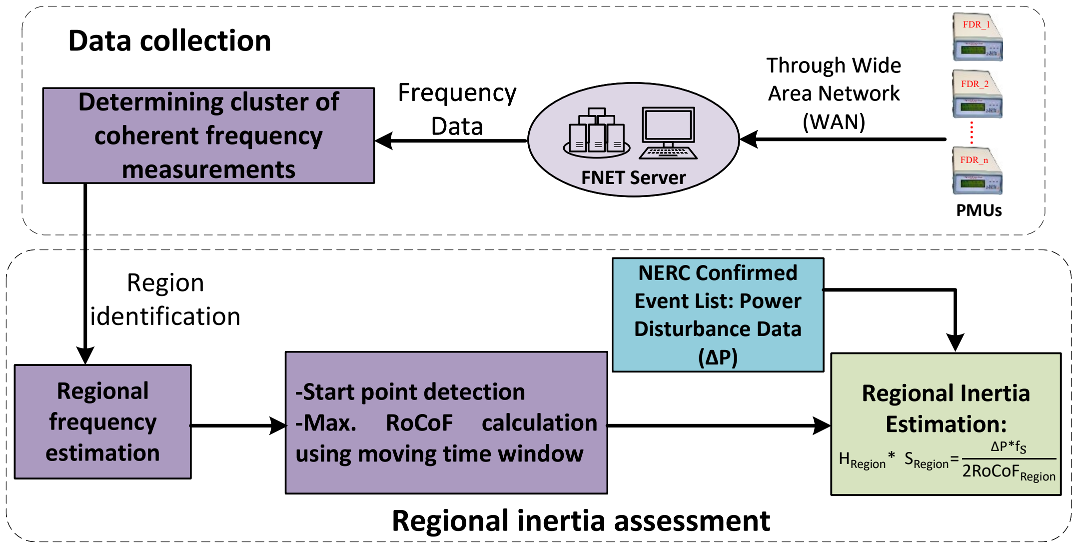

Fig. 3. Framework for event-based inertia estimation.

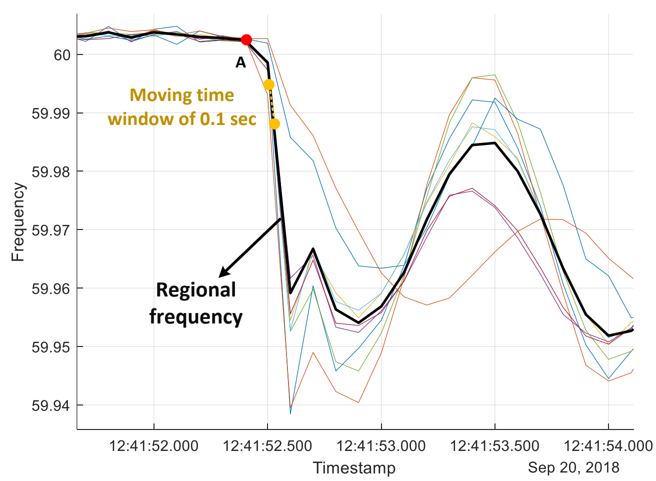

Fig. 4. Regional frequency response showing the event start point and RoCoF calculation method.

(3). The averaging method used in this framework helps to mitigate the impact of anomalous measurements and noise in the regional frequency estimated. Once the regional frequency is estimated, the event start point detection is the next step in the method. The event start time is key to accurately estimate the event RoCoF. To precisely determine the start point, we can use the following expression that calculates the maximum change in RoCoF.

$$Diff = max \left| Pre_{RoCoF(t)} - Post_{RoCoF(t)} \right| \tag{4}$$

where $Pre_{RoCoF(t)}$ and $Post_{RoCoF(t)}$ are the RoCoFs calculated before and after each time point including the actual start time point "A", represented by the red color in Fig. 4. In order to avoid any significant, non-event-related changes surrounding the event, the RoCoF difference is calculated from 8-10 seconds before the event starts.

We propose a hybrid methodology that combines the advantages of the two RoCoF estimation approaches: window and non-window-based methods. This method is based on a mean value of frequency measurements collected from all FDRs, which has the effect of mitigating minor noises. This inherents from the noise-removal capabilities of window-based systems. Further, it includes calculating RoCoF continuously using a sliding 0.1-second window, thus maintaining a level of temporal resolution, a major characteristic of non-window-based RoCoF estimation. This dual strategy ensures both robustness against noises and granularity in capturing rapid frequency dynamics.

Aligning with NERC standards, this method calculates RoCoF within the first 0.5 sec after the event [12], which can effectively capture the inertial response. We then choose the maximum RoCoF among the calculated RoCoFs. So the moving window within 0.5 seconds allows pinpointing the exact peak RoCoF, which might be missed with larger windows or non-window methods that are too noisy. By focusing on the transient phase, where system behavior is most dynamic, the hybrid approach optimizes accuracy when it matters most.

V. Results and Discussion

In 2023, NY was ranked fourth in the nation in solar power generation. Solar energy accounted for about 5% of the total energy generation of New York, and wind energy accounted for almost 4% of NY's total energy generation [13]. With the growing rise in the generation and investment in renewables, the inertia assessment of NY is needed.

There are six confirmed events that occurred between 2017 and 2022 in NY. Table I summarizes detailed information on the estimation of inertia during such events. It includes key

TABLE I
COMPREHENSIVE INERTIA EVENT ANALYSIS FOR NY REGION

Event Number	1	2	3	4	5	6
Event Date (UTC)	10/8/2017 17:08	2/3/2018 13:35	8/27/2018 4:32	9/20/2018 12:41	7/12/2019 0:45	7/6/2022 19:54
Power Mismatch (MW)	657	1302	1270	1250	1493	1176
Intercon Max RoCoF (Hz/s)	1.09E-02	8.43E-03	2.16E-02	1.36E-02	1.22E-02	8.95E-03
NY RoCoF (Hz/s)	8.31E-01	7.88E-01	7.89E-01	2.36E-01	1.09E+00	4.33E-01
Local RoCoF (Hz/s)	1.19E+00	1.30E+00	2.05E+00	3.20E-01	1.75E+00	7.91E-01
$H_{intercon}$ **(MVA·s)**	1.80E+06	4.63E+06	1.76E+06	2.76E+06	3.68E+06	3.94E+06
H_{NY} **(MVA·s)**	2.37E+04	4.96E+04	4.83E+04	1.59E+05	4.12E+04	8.14E+04
H_{local} **(MVA·s)**	1.66E+04	3.00E+04	1.86E+04	1.17E+05	2.57E+04	4.46E+04
FDR$_{nearest}$	FDR826	FDR826	FDR826	FDR1403	FDR826	FDR826
Inertial Support Arrival Time (sec)	0.9	0.7	1.1	0.6	0.6	0.7
$H_{NY}/H_{intercon}$ **(%)**	1.32%	1.07%	2.74%	5.75%	1.12%	2.07%

metrics such as the local RoCoF, local inertia, regional RoCoF, regional inertia, and the inertial arrival time. Here, local RoCoF is determined using the FDR that is closest to the event location. This measurement is essential for understanding how local systems respond to perturbations. On a more regional level, the regional RoCoF portrays the overall RoCoF of the entire NY region by evaluating frequency changes across all FDRs in the area. This provides valuable insights into the region's frequency response capabilities during such events.

For instance, Event 4 on September 20, 2018, happened in the Fall season and exhibited a substantial mismatch of 1250 MW. Surprisingly, the regional RoCoF remained relatively moderate at 0.236 Hz/s. This low RoCoF level due to significant power mismatch can likely be attributed to robust system inertia. It is linked with the high availability of conventional generation resources during this period. On the other hand, Event 6 on July 6, 2022, which occurred during a peak summer month—a time traditionally associated with high air conditioning load—witnessed a similar mismatch of 1176 MW. However, the NY RoCoF increased to 0.433 Hz/s. This may be attributed to the increasing reliance on variable renewable energy sources like wind and solar, which do not contribute to rotational inertia. This exacerbates the impact of disturbances on system stability.

The inertia support arrival time can be defined as the difference in time between the earliest frequency drop and the interconnection frequency drop. This parameter demonstrates whenever a contingency occurs in NY, then how much time it takes to receive the inertia support from the interconnection level. The results show an average of around 0.8 sec of inertia support arrival time. The interconnection inertia is determined by using the RoCoF of the interconnection frequency dynamics. The method uses the technique in line with [14] to determine the interconnection inertia. From the results, we observe that NY contributes approximately 2.5% to the total inertia of the EI.

VI. CONCLUSION

In this paper, the inertia assessment of NY is carried out utilizing real events. We proposed and implemented a hybrid method of RoCoF estimation that contributes to a more robust and accurate inertia assessment. Furthermore, various inertia metrics are calculated, which help to find the insights of the regional dynamics during events. The regional inertia of NY is compared to that of the EI. The analysis of the results indicates that with the rise in IBRs, RoCoF levels are increasing, which highlights the need for strategic planning of frequency support methods. Future work includes application of the proposed method to other regions of the US. Also, the region identification technique will be made more comprehensive and refined.

ACKNOWLEDGMENT

This material is based upon work supported by the US Department of Energy, Office of Electricity (OE) under contract DE-AC05-00OR22725.

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