Dr. Yashasvi Bansal

Post Doctoral Research Associate (IIT Kanpur)
Electrical Engineering, Indian Institute of Technology Kanpur
yashasvib@iitk.ac.in | yashasvi.bansal04@gmail.com
+91-9877668117
Web | Linkedin | GoogleScholar

EDUCATION

Doctor of Philosophy | ***Power Engineering*** | **CGPA : 9.67** July 2016- Sept. 2021

- Indian Institute of Technology Ropar, Rupnagar, Punjab.
  - Thesis Title: Fault Detection, Isolation and Reconfiguration in Active Distribution Networks using MicroSynchrophasors.
  - Course Work: Simulation and Analysis of Modern Power System, Power System Protection, Power System Dynamics Stability and Control, Modeling Simulation and Optimization Techniques.

Master of Technology | ***Power Systems*** | **CGPA : 9.75** July 2012- June 2014

- Thapar University, Patiala, Punjab.
  - Thesis Title: Optimal Sectionalizer Placement in Radial Distribution System using Mutation Assisted Particle Swarm Optimization.

Bachelor of Technology | ***Electrical & Electronics Engineering*** | **78.70 %** July 2008- June 2012

- Uttarakhand Technical University, Dehradun.
  - Final year project: Simulation of MHO Characteristics for Transmission Line Protection using PSCAD.
  - Third year project: Portable Mobile Charger (Talking Walking-TWking Green Charger) based on Faraday's Laws of Electromagnetic Induction.

AREA OF INTEREST

- Smart grid, Distributed renewable energy resources, Protection, Wide-area monitoring and control of medium/ low voltage grids, Synchrophasor technology and its applications, Artificial Intelligence techniques, Smart home energy management, Cyber-security, Power system resiliency and reliability.

RESEARCH EXPERIENCE

PhD Research

- Developing a frequency estimator suitable for protection applications in Active Distribution Networks (ADNs).
- Developing a Protection class (P-class) MicroSynchrophasor (μPMU) algorithm considering the ADN requirements.
- Devising a new deterministic approach for the fault detection and localization using μPMU information.

- Developing a technique for Islanding detection with insignificant Non-Detection Zone using μPMU information at the point of common coupling.
- Formulating a partitioning based reconfiguration algorithm using meta-heuristic algorithm, valuing the presence of renewable energy resources.
- Real-time validation with the help of Real-Time Digital Simulator (RTDS) and/or dSPACE-1104 (real time controller) on the IEEE-13, IEEE-34 and IEEE-123 Bus Distribution Feeder integrated with PhotoVoltaic (PV) Distributed Generation (DG)s.

M.Tech Project

- This project explores value-based reliability planning approach to determine the number and location of sectionalizers. A solution methodology based on the heuristic Mutation Assisted Particle Swarm Optimization (PSO) is proposed to avoid premature convergence of PSO. The optimization is directed to utilize system expected outage cost and switches cost, in association with system average interruption duration index as two single objective functions. The proposed method is implemented using fuzzy decision making approach for the IEEE 12-bus, 33-bus and 47-bus distribution system.

B.Tech Project

- The final year project offers an economical and feasible alternative to investigate the performance of relays and protection systems using modelling of protective relays. MHO characteristics and Bergeron model type transmission line are modelled and simulated using PSCAD software. The work provided the envisions to research that can help to extend the availability of technology and its usage in the support of electric grid.
- The third year project aims at developing a charger "The TWking green charger" –the Talking-Walking green charger using Faraday's Law of Induction. The household waste is used to develop the charger, and the charger is attached to the shoe. The device uses the naturally occurring, vibrating, shock forces that are concentrated at the knee or ankle during walking. It was a solution towards a clean, portable and inexpensive source of energy to charge mobile phones.

Post Doctoral Research Experience

Research Associate | Indian Institute of Technology Kanpur Nov 2021- Till date

- Distribution System Resilience and Phasor Measurement Unit (PMU)

Teaching Experience

Teaching Assistantship | Indian Institute of Technology Ropar July 2016- June 2021

- Principle of Electrical Engineering, Power Systems, Simulation and Analysis of Modern Power Systems, Electromechanics Laboratory and Real-Time Digital Simulation (RTDS) Laboratory Development.

Assistant Professor | National Institute of Technology Delhi July 2015- May 2016

- Basics of Electrical and Electronics Engineering, Power System Analysis, Power System Protection, Artificial Intelligence, and Power System Simulation Lab

Lecturer | Thapar University July 2014- Dec 2014

- Electromagnetic Field Theory and Power Systems Lab

Teaching Assistantship | Thapar University July 2012- June 2014

- Computer Aided Analysis of Power System, Basic of Electrical Engineering Lab and Machines Lab

MENTORING EXPERIENCE

B.Tech Final Year Projects | National Institute of Technology Delhi July 2015- May 2016

- Muscle movement detection using Surface Electromyography (EMG).
- Simulation study of single and double area Load Frequency Control (LFC).

Summer Intern | Indian Institute of Technology Ropar May 2019- July 2019

- A Simple Passive Islanding Detection Method to reduce the Non Detection Zone of Over/Under Voltage and Over/Under Frequency Relays

SKILLS

- **Programming Language:** MATLAB, C/C++
- **Simulation Software:** MATLAB-SIMULINK, PSCAD, RSCAD, SCILAB, POWERWORLD
- **Hardware:** dSPACE1104, RTDS, SELPMU-451, SEL-2404, Doble-F6350e, WAMSTER PMU
- **Document:** Latex, MS, Powerpoint, Visio, Adobe Photoshop

HONORS AND AWARDS

- POSOCO Power System Award - 2021 for the PhD thesis by Power System Operation Corporation Limited (POSOCO), Government of India, 2021.
- Received best paper award for the paper entitled "An Adaptive IIR Notch Filter based Half-Cycle P-Class Phasor Measurement Estimation Scheme," in the session "Power System Measurement," at 8^{th} International Conference on Power Systems (ICPS), Jaipur, India, 2019.
- Awarded University Medal for securing the highest CGPA in the M.E. in Power Systems, Thapar University, Patiala, Punjab, India, 2014.
- Got selected for participation in the Interactive event organized on the occasion of the visit of His Excellency, Dr. A.P.J. Abdul Kalam, President of India, in G.B. Pant University of Agriculture and Technology, Pantnagar, November, 2003.

PUBLICATIONS

Journals-Published/Accepted

1. Y. Bansal and R. Sodhi, "A Novel Frequency Estimator for Protection Applications in Active Distribution Networks," in **IEEE Transactions on Industry Applications**, early access, doi: 10.1109/TIA.2022.3164019.
2. Y. Bansal and R. Sodhi, "A Statistical Features Based Generic Passive Islanding Detection Scheme for IIDGs System," in **IEEE Transactions on Power Delivery**, early access, doi: 10.1109/TPWRD.2021.3124986.
3. Y. Bansal and R. Sodhi, "A novel µPMUs assisted loss-of-mains detection technique for active distribution systems," in **Electric Power Systems Research**, vol. 202, pp. 107578, 2021, doi: 10.1016/j.epsr.2021.107578.
4. Y. Bansal and R. Sodhi, "A Half-Cycle Fast Discrete Orthonormal S-Transform-Based Protection-Class μPMU," in **IEEE Transactions on Instrumentation and Measurement**, vol. 69, no. 9, pp. 6934-6945, Sept. 2020, doi:10.1109/ TIM.2020.2980339.

5. Y. Bansal and R. Sodhi, "μPMUs Enabled Tellegen's Theorem-Based Fault Identification Method for Unbalanced Active Distribution Network Using RTDS," in **IEEE Systems Journal**, vol. 14, no. 3, pp. 4567-4578, Sept. 2020, doi:10.1109/ JSYST.2020.2976736.

6. Y. Bansal, M. V. Reddy and R. Sodhi, "An Open Loop Frequency Estimator for Adversely Distorted Signals En-compassing Interharmonics," in **Electric Power Components and Systems**, vol. 4, no. 13, pp. 1218-1229, 2019, doi:10.1080/15325008.2019.1660737.

Journals-Communicated

1. Y. Bansal, R. Sodhi, S Chakrabarti, and A. Sharma "A Novel Two-stage Partitioning based Reconfiguration Method for Active Distribution Networks," in **IEEE Transactions on Smart Grid, 2022**.

Conferences

1. Y. Bansal and R. Sodhi, "Adapting Tellegen's Theorem for Synchrophasor-Assisted Fault Identification in Active Distribution Networks - An Illustration," 21^{st} **National Power System Conference (NPSC)**, Gujarat, India, 2020, doi: 10.1109/NPSC49263.2020.9331882.

2. Y. Bansal and R. Sodhi, "A Novel Frequency Estimator for Protection Applications in Active Distribution Networks," 21^{st} **National Power System Conference (NPSC)**, Gujarat, India, 2020, doi: 10.1109/NPSC49263.2020.9331839.

3. Y. Bansal and R. Sodhi, "An Adaptive IIR Notch Filter based Half-Cycle P-Class Phasor Measurement Estimation Scheme," **8th International Conference on Power Systems (ICPS)**, Jaipur, India, pp. 1-6, 2019, doi: 10.1109/ICPS48983.2019.9067648.

4. Y. Bansal and R. Sodhi, "Microgrid fault detection methods: Reviews, issues and future trends," **IEEE Innovative Smart Grid Technologies - Asia** (ISGT Asia), Singapore, pp. 401-406, 2018, doi: 10.1109/ISGT-Asia.2018.8467938.

5. Y. Bansal, V. Khugsal and R. Padarla, "Simulation of MHO Characteristics for Transmission Line Protection using PSCAD," **International Journal of research in Engineering and Applied Sciences (IJREAS)**, vol. 2, Issue 2, pp. 540-550, Feb. 2012.

Workshops And Courses

- One day training on, "Efficient Energy Management System for Smart Residential Networks via Mobile Web Applications ", organized under the Social Scientific Responsibility Program, supported by Science and Engineering Research Board (SERB), IIT Ropar, Oct 2021.
- Short course on, "Advanced Modelling of DER-Rich Active Distribution Networks ", Department of Electrical and Electronic Engineering, The University of Melbourne, Australia, August 2021.
- Four days webinar on, "Understanding Blockchain," conducted as a part of the SWE IIT Ropar Global Engineering Conference, January 2021.
- Five days workshop as "Statistical Techniques for AI and Data Science," organized by Indo-Taiwan Joint Research Centre on AI ML, IIT Ropar, Dec 2019.
- One day workshop on, "RTDS Simulator Introductory Training," by RTDS Technologies Inc., Canada, Jan 2019.
- Three days workshop on "Power Engineering Research and Applications-PERA'18," organized by IEEE PES student branch chapter, IIT Kanpur and IEEE PES/IAS Joint chapter Uttar Pradesh, Nov 2018.

- Five days GIAN course on "Recent trends in Protection of Microgrids with high DER penetration: Issues, Challenges and Mitigation," delivered by DR. Mukesh Nagpal, Principal Engineer and Manager BC Hydro, Canada and organized by Delhi Technological University, Delhi, Feb 2018.
- Five days GIAN course on "Integration of Electronically-Coupled Energy Resources and Apparatus in Electrical Power Systems," delivered by Prof. Reza Iravani (University of Toronto Canada) and organized by IIT Bhubaneswar, Feb 2018.
- One day seminar on, "Industrial Automation using PLC and SCADA, " by APTRON at NIT Delhi, March 2016.
- Course on, "Language C," conducted in College of Engineering Roorkee and organized by Indian Institute of Robotics, 2012.
- Two days workshop on, "Scilab," organized by Fillip Foundation and funded by NMEICT, MHRD through IIT Bombay, 2011.

Professional Services / Activities

Project (Team Member)

- Project ETA-422/2016, Setting up RTDS facility at IIT Ropar, funded by Department of Science and Technology, New Delhi.
- Project CRG/2018/000084, Efficient Energy Management System for Smart Residential Networks Via Intelligent Web based Services, funded by Core Research grant, DST-SERB, New Delhi.

Memberships

- IEEE Student Member, 2017-2020.
- IEEE Graduate Student Member, 2020 - Present.
- IEEE Power and Energy Society Member, 2018- Present.
- IEEE Young Professionals, 2018-Present.
- IEEE Women in Engineering, 2019-Present.
- Technical Programme Committee Member, IEEE International Conference on Power System (ICPS) -2021, IIT Kharagpur.

Peer-Reviewed Services

- Reviewer, IEEE Transactions on Instrumentation and Measurement.
- Reviewer, IEEE Systems Journal.
- Reviewer, IEEE Transactions on Smart Grid.
- Reviewer, IET Generation, Transmission and Distribution.
- Reviewer, Electric Power Systems Research.
- Reviewer, Electric Power Components and Systems.
- Reviewer, International Journal of Electrical Power Energy Systems
- Reviewer, International Conferences as GM PES, NPSC, ICPS.

Volunteer Services

- Plenary Talk and session anchor in 13^{th} IEEE International Conference on Industrial and Information System (ICIIS) - Dec 2018, IIT Ropar.
- In core organizing committee of one week training on, "Real Time Digital Simulator (RTDS) set-up," Jan 2019, IIT Ropar.
- In core organizing committee of two-days training on, "F6350e Voltage/ Enhanced Current Amplifier," organized by SYMAR Lab IIT Ropar, April 2021.

Extra/ Co-Curricular Achievements

- Successfully completed 11km IIT Ropar run conducted on 2^{nd} October, 2019.
- Team member of Women's Cricket Team, Indian Institute of Technology Ropar, Punjab, 2017-18.
- Stood first in Badminton (women) at Inter Year Sports Championship 2017, the Annual Intra IIT Sports, held during Jan-Feb 2017.
- Member of Technical Club, and Newsletter Editorial Board of National Institute of Technology Delhi, New Delhi during the session 2015-16.
- Member of Technical Committee in College of Engineering Roorkee, Roorkee during the session 2009-10.
- Got first position in Drawing and Painting Competition organized by Vivekananda Swadhyay Mandal, National Service Scheme & Sanskritik Chetna Parishad, 2007.
- Stood first in Extempore Competition organized by Gandhi Bhavan during Gandhi Utsav, G.B.Pant University of Agriculture and Technology, Pantnagar, 2006.
- Special prize in Motivation for Blood Donation by Board of Directors and Committee Chairpersons, Rotary Club Pantnagar, November 2006.
- Stood first in Drawing competition organized by Department of Environmental Sciences, G.B.Pant University of Agriculture and Technology on World's Environment Day, June 2007.

Personal Details

- Date of Birth : September 04, 1990.
- Nationality : Indian.
- Martial Status: Unmarried.
- Postal Address: Room No. S428, RA Tower, IIT Kanpur, Uttar Pradesh-208016.
- Permanent Address: I/ 144, Phool Bagh, GBPUA&T, Udham Singh Nagar, Uttarakhand-263145.

Referees

[1] Dr Ranjana Sodhi
Associate Professor,
Department of Electrical Engineering,
Indian Institute of Technology Ropar,
email: rsodhi@iitrpr.ac.in.

[2] Prof Saikat Chakrabarti
Professor,
Department of Electrical Engineering,
Indian Institute of Technology Kanpur,
email: saikatc@iitk.ac.in.

[3] Prof Sanjay Jain
Professor,
Department of Electrical and Instrumentation Engineering,
Thapar University, Punjab,
email: skjain@thapar.edu.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TIA.2022.3164019, IEEE Transactions on Industry Applications

A Novel Frequency Estimator for Protection Applications in Active Distribution Networks

Yashasvi Bansal, *Member, IEEE,* and Ranjana Sodhi, *Member, IEEE*

***Abstract*—Frequency is a useful parameter for ensuring the proper functioning of the power system operation, control, and protection. In this paper, a fast and accurate Frequency Estimator (FE) is developed using a zero-crossing and a peak, occurring in the buffered data, unlike the commonly used two zero-crossings. Prior to this, the signal is pre-processed using the Sliding Goertzel Filter (SGF) that mitigates the impact of undesirable features such as harmonics, noise, etc., from the signal. The two FEs, with and without SGF, then work in tandem to form the hybrid estimator and named as $Z_C P_k$-HFE. The estimated frequency is chosen based on the minimum error computed from the two parallel estimators. The performance of the estimator is, then, validated using the simulated signals polluted with harmonics, noise, transients etc. The paper also discusses the protection-oriented applications of the proposed FE in Active Distribution Network (ADN). Moreover, the evaluation results with the real-time field data and the IEEE-13 ADN incorporated with PhotoVoltaic (PV) using dSPACE1104 and Real Time Digital Simulator (RTDS) show its capability to estimate the real-time frequency with satisfactory output.**

***Index Terms*—Distributed Generation, dSPACE1104, Real Time Digital Simulator, Sliding Goertzel, Zero Crossing Detector**

I. Introduction

The estimation of frequency is a well-defined problem in the field of power systems, where the frequency value fluctuates over a short allowable range due to continuous load variation in the system. The problem of accurate frequency estimation becomes further challenging when the estimation is done at the distribution-level [1], where:

- the signal is corrupted with noise,
- the signal is polluted with various harmonics and inter-harmonics,
- the signal encounters various power quality events such as, phase jumps, voltage sags, etc.,
- the signal undergoes various kinds of dynamics due to the ever-increasing integration of Distributed Generation (DGs) in electric distribution systems; transforming the passive networks into Active Distribution Networks (ADNs) or Microgrid (MG).

A MG can work in two operational modes viz., Grid-connected mode and Standalone mode. To facilitate the seamless transition between the modes, frequency acts as a key feature in the MG control scheme. IEEE Standard 1547 [2] suggests that the difference between MG and grid frequency should not exceed $0.1\ \%$ during MG reconnection to the grid. Although the frequency is permitted to deviate within the allowable band in conformity with the National Electricity Grid Codes, the continuous monitoring with a rapid response is the pressing priority for applications such as fault detection [3], load shedding, generator protection [4], islanding detection [5], etc. Besides this, other frequency aimed fields are load-frequency control, renewable energy control, and open-loop based distribution-level Phasor Measurement Units (D-PMUs) [6] that require prior frequency information for the parameter estimation. It, therefore, becomes imperative to accurately measure the signal frequency under the various distorted conditions, i.e., noise, harmonics, frequency drift, phase jumps, voltage sags, etc., that too in a fast manner.

In the literature, several methods have been documented, among which Zero Crossing dependent Detector (ZCD) is the most common and simplest frequency estimation technique [7]. However, the technique gives large error when the actual signal is contaminated with harmonics and noise. The limitation associated with ZCD is resolved in [8] using Non-linear Least Error Squares (NLES) algorithm. The sampled signal is, at first, convoluted with the filter coefficients that provide approximated frequency. Then, this frequency information and cycle length are fed to NLES, which provides the final fundamental frequency. The method is computationally efficient and maintains good accuracy during various steady and dynamic conditions.

Another common class of algorithm is Frequency or Phase Locked Loop (FLL or PLL) [9]–[11], which has turned into cutting-edge technology for grid synchronization. Although the PLL leads to undesirable frequency swings under faulty conditions, it can be minimized by using the FLL concept. In general, these are light to execute on a real-time processor, but their output depends heavily on the parameter tuning to provide an adequate trade-off between dynamic response and precision. In [9], an elaborative comparative study is performed for the various Orthogonal-Signal-Generator-based PLLs (OSG-PLLs). The study uncovers the benefits and drawbacks of various PLLs. In [10], a Frequency-Fixed SOGI (FF-SOGI) based PLL is presented, and its performance is found to be similar to the standard SOGI-PLL. Nonetheless, the dynamic performance of the Second-Order Generalized Integrator (SOGI)-PLLs/FLLs is improved in [11] using the non-adaptive discrete-time FLL. Since the method is affected by the presence of harmonics and DC-offset in the grid signal, the cascaded discrete-time pre-filters are employed at the cost of a poor dynamic performance.

Yashasvi Bansal is with the Department of Electrical Engineering, Indian Institute of Technology Kanpur, UP, 208016, India, e-mail:yashasvi.bansal04@gmail.com.

Ranjana Sodhi is with the Department of Electrical Engineering, Indian Institute of Technology Ropar, Punjab, 140001, India.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TPWRD.2021.3124986, IEEE Transactions on Power Delivery

A Statistical Features Based Generic Passive Islanding Detection Scheme for IIDGs System

Yashasvi Bansal, *Member, IEEE,* and Ranjana Sodhi, *Member, IEEE*

***Abstract*—This paper proposes a new passive Islanding detection approach for the Inverter Interfaced Distributed Generators (IIDGs) operating under different control modes. First, a novel index is formulated using Root Mean Square (RMS) value of the voltage and the frequency information, acquired at the Point of Common Coupling (PCC) of the target DG. The index is then post-processed by estimating the number of peaks and valleys (N_{p_k-v}) in a cycle using the sliding window concept, which indicates the occurrence of an event. Finally, the nature of the event, i.e., Islanding or non-Islanding, is decided by exploiting the two statistical features *viz.*, Square of RMS (S_{RMS}) of N_{p_k-v} and Average Crest Factor (ACF^m) of the proposed index. The performance of the proposed method (P-IDM) is demonstrated through comprehensive studies in PSCAD/EMTDC for the single-bus and IEEE 34-bus Active Distribution System (ADS). Also, the real-time validation is performed for the IEEE 34-bus using Controller Hardware-in-the-Loop (CHIL) setup comprising of Real-Time Digital Simulator (RTDS) and dSPACE1104. The simulation and hardware results for different test systems indicate that the proposed scheme, being generic in nature, sustains its efficacy under various interface controls of IIDGs. Finally, a comparative assessment with the other existing Signal Processing (SP) based passive methodologies shows the supremacy of the proposed method in terms of accuracy and faster detection.**

***Index Terms*—Inverter Interfaced DGs, Non-Detection Zone, Passive Islanding Detection, PSCAD, RTDS, dSPACE1104**

ABBREVIATIONS

ADS	Active Distribution System
CB	Circuit Breaker
CHIL	Controller Hardware in the Loop
DG	Distributed Generators
DT	Detection Time
DWT	Discrete Wavelet Transform
IIDG	Inverter Interfaced Distributed Generators
IDM	Islanding Detection Method
LRF	Low Resistance Faults
NDZ	Non-Detection Zone
PCC	Point of Common Coupling
P-IDM	Proposed Islanding Detection Method
PV	PhotoVoltaic system
μPMU	micro Phasor Measurement Unit
RMS	Root Mean Square
RTDS	Real Time Digital Simulator
SP	Signal Processing

Yashasvi Bansal is with the Department of Electrical Engineering, Indian Institute of Technology Kanpur, Uttar Pradesh, 208016, India, e-mail:yashasvi.bansal04@gmail.com

Ranjana Sodhi is with the Department of Electrical Engineering, Indian Institute of Technology Ropar, Punjab, 140001, India, e-mail:rsodhi@iitrpr.ac.in

I. INTRODUCTION

Unintentional Islanding is a situation when any portion of the distribution system is electrically isolated from the main source of supply, yet is energized by Distributed Generators (DGs). This unpleasant dynamic phenomenon can bring unsafety to maintenance personnel, severe damage to equipment, power quality problems, out of reclosing and other operational as well as protection issues. As a result of its ill-effects, detection of an Islanding situation within 2 s has turned into an obligatory requirement for the DGs as per various standards such as UL 1741 Standards (Std.) [1] and IEEE Std. 1547-2018 [2]. Consequently, the problem of timely and accurate Islanding detection has gained lots of attention in recent times.

Islanding Detection Methods (IDMs) can be broadly classified into two major classes, i.e., Remote and Local methods. Commonly, remote methods utilize communication link between utility grid and DGs such as [3], [4] and [5] In [3], the signal is broadcasted from the substation to the DG site through signal paths as distribution feeders. In case the signal is not detected, the DG is considered as Islanded. In [4], the data from phasor measurement units is collected from different locations at microgrid control center. The collected data is then reduced through principal component analysis, and characterized using multi-resolution Teager energy operator. The method detects the Islanding in 0.25 s with Non-Detection Zone (NDZ) of 1%. In wide-area IDM [5], the two phasor measurement units exchange their synchrophasors using relay-to-relay communication technique with NDZ as 15%, 5% and 3% for Under/ Over Voltage (UV/OV), Under/Over Frequency (UF/OF) and rate of change of frequency as passive parameters, respectively. Hence, remote methods are ineffective to power quality disturbances as they do not inject any deliberate disturbance in the system. But, they are considered to be costly, less reliable owing to failure under communication loss, and also, impractical for small scale Active Distribution System (ADS).

The local IDM are further classified as active, passive and hybrid methods. Active methods are based on observing the signal parameters by injecting intentional perturbation using the existing controller, or at times, using the external device or external controller. References [6] and [7] involve signal injection or application of positive feedback in the inverter control. In [6], a signal injection of 1% of d-axis current reference with 20 Hz frequency is used to generate disturbance. Furthermore, in [7], a disturbance is injected into the maximum power point tracking controller when an absolute deviation of the output voltage crosses a threshold. Generally,

Electric Power Systems Research 202 (2022) 107578

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A novel μPMUs assisted loss-of-mains detection technique for active distribution systems

Yashasvi Bansal *, Ranjana Sodhi

Department of Electrical Engineering, Indian Institute of Technology, Ropar 140001, India

ARTICLE INFO

Keywords:
Loss of mains
Adjoint network
Tellegen's theorem
Micro phasor measurement units
Distributed generation
Real-time digital simulator
dSPACE1104

ABSTRACT

In this paper, a novel Loss-of-Mains (LoM) detection scheme is proposed using the Adjoint Network principle with limited number of installed micro Phasor Measurement Units (μPMU)s. The proposed scheme is comprised of two main stages viz., Off-line and On-line. In first stage, the network graph is divided into separate zones with two different Adjoints for each zonal area. The phasor information of the Adjoints are stored in matrices, as needed in the real-time process. The next step begins with Zonal Event Detection (ZED), which shrinks the LoM search area and ends up identifying the exact Point of Disconnection (PoD) using the Tellegen's Theorem in a ZED defined area. The major advantage of the suggested approach is that its reliability is independent of both the circumstances of the power mismatch and DG type. The efficacy of the proposed method is demonstrated through various simulated test cases and also, validated through Hardware-in-the-Loop (HIL) testing using Real-Time Digital Simulator (RTDS) and dSPACE1104 micro-controller on an unbalanced IEEE 13-bus distribution system integrated with PhotoVoltaic (PV) DGs.

1. Introduction

Nowadays, integration of renewable resources based Distributed Generation (DG) to Distribution System (DS) has increased significantly in an attempt to move toward a more sustainable and environmental-friendly energy system. This inclusion of DGs, however, has brought up various challenges in the protection, monitoring and control of the electric power system [1]. A Loss-of-Mains (LoM, also known as islanding) is one of such undesirable event that occurs when the transmitting power from the Grid is lost. This can lead to sudden development of island that causes issues related to power quality and synchronization. Moreover, it poses a high risk to the line workers during the service restoration. Therefore, it becomes imperative to precisely detect the LoM condition within 2 s, as suggested by the IEEE std. 1547-2018 [2].

As per the literature, various techniques have been developed to detect LoM that are broadly classified into passive, active and remote [3]. These techniques holistically make use of parameters that reflect any changes in the operating state of the system. Hence, the deployment of micro-Phasor Measurements Units (μPMU)s [4] in the DS enhances the efficiency of LoM techniques. Therefore, in the present paper, the emphasis is given to the methodologies that employ output of μPMU (voltage/current magnitude, phase angle, frequency, and rate of Change of frequency) to detect LoM. Passive methods are based on the continuous monitoring of parametric changes at the local DG site, that can also be observed by the installed μPMUs at Point of Common Coupling (PCC). There are lot of parameters used by the researchers to detect LoM such as, under/over frequency and voltage, rate of change of voltage phase angle/ reactive power etc. In [5], the authors calculated auto-correlation factor of the three-phase voltage signal using the full-cycle modified Discrete Fourier Transform (DFT) algorithm. The factor calculates similarity level between observations at present and their lagged versions. The method performs well in zero power imbalance, but at the cost of high detection time i.e., 3 cycles. Phaselet phasor estimation based LoM detection is proposed in [6]. The method is sensitive to harmonics due to the phaselet computation over fractional window length. In [7], the author selected parameters such as, rotor angle deviation, frequency and rate-of-change-of-frequency (RoCoF) that are transformed into three dimensional polarization ellipse. Similarly, in [8], the feature selection is carried out using the S-transform to calculate the frequency and energy of the voltage signals. These method possess high detection time due to its multi-feature processing. The common issues faced by these passive oriented methods are the predetermined possibility of large Non-Detection Zone (NDZ) and nuisance trip in critical non-LoM conditions.

* Corresponding author.
E-mail address: yashasvi.bansal@iitrpr.ac.in (Y. Bansal).

https://doi.org/10.1016/j.epsr.2021.107578
Received 3 March 2021; Received in revised form 2 August 2021; Accepted 8 September 2021
Available online 20 September 2021
0378-7796/

A Half-Cycle Fast Discrete Orthonormal S-Transform-Based Protection-Class μPMU

Yashasvi Bansal, *Student Member, IEEE*, and Ranjana Sodhi, *Member, IEEE*

***Abstract*— This article proposes a novel, fast discrete orthonormal Stockwell transform (FDOST)-based protection-class microphasor measurement unit (P-μPMU) algorithm. The proposed algorithm provides very fast and high-resolution measurements of the system state, which are then expected to serve various active distribution networks (ADNs) protection applications, e.g., islanding detection and fault detection. The phasors are estimated from FDOST, utilizing the half-cycle discrete Fourier transform (DFT). The two major concerns of the half-cycle FDOST with respect to the response in the presence of even harmonics and off-nominal frequency are handled using the even harmonics filtration (EHF) and half-cycle sample value adjustment (HC-SVA), respectively. Since both of these techniques, namely, EHF and HC-SVA, require system frequency as the input, a new peak and zero-crossing-based hybrid frequency estimator (PZC-HF$_E$) is also proposed in this article. The performance of the proposed methodology is evaluated for various simulated scenarios as per the IEEE Std. C37.118.1a-2014, as well as in the hardware setup. The results of the proposed P-μPMU algorithm are also compared with two other methodologies, i.e., the Hilbert transform and convolution based PMU (HTC-PMU) and two-cycle interpolated discrete Fourier transform-based PMU (IpDFT-PMU) using the hardware setup. The test results reveal the superiority of the proposed P-μPMU algorithm over the compared methods in terms of response time and the estimation accuracy.**

***Index Terms*— dSPACE1104, fast discrete orthonormal Stockwell transform (FDOST), frequency estimator F$_E$, half-cycle discrete Fourier transform (HC-DFT), microgrid, phasor measurement unit (PMU), protection-class (P-class), real-time digital simulator (RTDS), zero-crossing detector (ZCD).**

I. Introduction

THE synchrophasor measurement units (PMUs)-based wide-area monitoring, protection and control (WAMPAC) system is quite mature at the transmission-level grid now [1]. Inspired from the immense benefits that this synchrophasor technology inherits, researchers are now exploring the feasibility of its usage at the distribution-level networks too [2]. The main motivation behind using such a technology at the distribution level is the ever-increasing penetration of renewable sources (RSs) at low- or medium-low-voltage levels of the grid, which, in turn, is giving rise to the active distribution networks (ADNs). Needless to say that the RS has helped in reducing the CO_2 emissions, transmission losses, and so on. However, their integration is also creating many potential challenges for the operation, control, and protection of the ADNs [3]. As an example, change in fault level, intermittent nature of the RS, nuisance tripping of the circuit breakers, relay miscoordination, reliability degradation due to the polluted signals with harmonics, and so on are some of the immediate issues for the ADN protection systems. Some preliminary studies reveal that the abovementioned protection-related issues can be well handled with the advent of μPMU-based ADN protection schemes [4], [5].

There exist many protection-class (P-class) or protection and measurement-class (P+M-class) PMU techniques in the literature, which are broadly classified as the discrete Fourier transform (DFT) and non-DFT-based methods. Many variants of DFT, such as interpolated discrete Fourier transform (IpDFT) based [6], [7], the Clarke transformation-based DFT (CT-DFT) [8], and quasi-positive-sequence DFT (Qps-DFT) [9], have been reported in the literature to estimate the phasor compatible with IEEE Std. C37.118.1a-2014 [10]. All these methods basically try to compensate for the spectral leakage, which arises because of the off-nominal frequency operation of the power system. The short-time Fourier transform (SFT)-based approaches, such as in [11] and [12], have also been reported, where the dynamic phasor estimation is improved by blending the SFT with the Taylor series derivatives but at the cost of the increased computational burden.

The non-DFT-based approaches include methods, such as in [13]–[17]. Affijulla and Tripathy [13] brought an idea of dictionary-based phasor estimation for the phase-angle estimation, least-square (LS) method utilizing the stored dictionary matrices for the estimation of magnitude, frequency, and the rate of change of frequency error (RFE). However, the parameterization with the LS increases the complexity. The other dynamic phasor estimation methods [14], [15] also employed the LS approach. In [16], the fundamental component is extracted using the Hilbert transform and convolution. In [17], the phasors are estimated based on approximation of Kth Taylor polynomial by means of the Taylor–Kalman–Fourier filter. However, the coefficient determination of the higher order polynomial model is computationally heavy.

Manuscript received September 20, 2019; revised January 21, 2020; accepted March 2, 2020. Date of publication March 12, 2020; date of current version August 11, 2020. This work was supported by FIST through DST, New Delhi, under IIT Ropar Project ETA-422/2016. The Associate Editor coordinating the review process was Ferdinanda Ponci. *(Corresponding author: Yashasvi Bansal.)*

The authors are with the Department of Electrical Engineering, IIT Ropar, Rupnagar 140001, India (e-mail: yashasvi.bansal@iitrpr.ac.in).

Color versions of one or more of the figures in this article are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TIM.2020.2980339

PMUs Enabled Tellegen's Theorem-Based Fault Identification Method for Unbalanced Active Distribution Network Using RTDS

Yashasvi Bansal, *Student Member, IEEE*, and Ranjana Sodhi, *Member, IEEE*

***Abstract*—The correct identification of the fault in the distribution systems can help in the healing process, system restoration, and thus lessen the duration of the outage. With the latest trend of penetrating the DG with the distribution network, the conventional fault identification (FI) methods become inappropriate for the promising active distribution network. Hence, the FI methods in the multisource, unbalanced, and weak distribution system is a challenge. In this article, the entire network is divided into the number of zones with each phase representing the two-port network. Further, the adjoint network matrices are formed for each of the two-port networks. The Tellegen's theorem based on adjoint circuit concept is then, used to identify the open-circuit section or the faulted node in the network using the input and output port information only. The voltage and current phasor information of the ports are acquired from the phasor measurement units based on the DFT. The methodology has been extensively verified on the IEEE-13 and IEEE-34 bus distribution systems integrated with the DGs, for all types of open and short circuit faults, with very encouraging results, with the real-time digital simulator.**

***Index Terms*—Active distribution network (ADN), fault identification (FI), open and short-circuit faults, phasor measurement unit (PMU), real-time digital simulation (RTDS), Tellegen's theorem.**

I. Introduction

In THE recent years, with the growing energy demand and attraction toward the renewable energy, the electric distribution system is witnessing radical topological transformation. The connection of the distributed energy resources in close proximity to the load, has modified the configuration of the distribution network from the single-ended source to a multiple source system. This further impacts the magnitude and direction of the fault current in the distribution network. Consequently, the intrinsic complexities of active distribution networks (ADNs) such as unbalanced structures, bidirectional power flow, the presence of laterals with distributed generators, multiended sources, etc., inhibit the direct application of established fault location approaches for the conventional radial distribution networks. In order to improve the network resiliency, redundancy, and reliability of the system, an efficient and accurate fault identification (FI) method is, thus, needed to speed up the restoration processes and to reduce the customer interruption cost allied with the outage.

Manuscript received June 26, 2019; revised December 10, 2019 and January 23, 2020; accepted February 21, 2020. Date of publication April 27, 2020; date of current version September 2, 2020. This work was supported by the FIST grant by the Department of Science and Technology, New Delhi, under IIT Ropar Project ETA-422/2016. *(Corresponding author: Yashasvi Bansal.)*

The authors are with the Department of Electrical Engineering, Indian Institute of Technology Ropar, Punjab 140001, India (e-mail: yashasvi.bansal@iitrpr.ac.in; rsodhi@iitrpr.ac.in).

Digital Object Identifier 10.1109/JSYST.2020.2976736

Technical literature reports a number of fault detection techniques that comprise of mainly model-based and data-driven methods in ADNs [1]. Model-based methodologies entail a comprehensive understanding of how the component works. Recently in [2], the fault is identified based on the phase differences between the positive sequence fault component of the bus voltage and current feeders. In [3], the sequence Thevenin equivalents of the sources are used with the voltage and current measurements at the connection of DG unit to determine fault section. The method assumes that digital fault recorders are fitted to record three-phase voltage or current phasor data. However, the technique requires fault contribution due to the DGs that are affected by the current transformer (CT) saturation and calculation errors. In [4], a communication-less method that uses voltage magnitude to decide the relay operating time is presented, whereas in [5], a communication-assisted method was proposed, where overcurrent and undervoltage relays are used for the purpose of fault detection in grid-connected and islanded modes of distributed system, respectively. But, it requires a backup protection in case of communication failure. Moreover, [4] and [5] suffers from slow response against the fault detection. In [6], transient monitoring function was measured from the inverter output current as local variable. However, the performance of the algorithm is dependent upon the moving window length used for the current waveform, longer windows improves the precision but reduce the speed and time response.

The data-driven methods are based on observing the data regarding the system or discovering the relation among the input and output state variables. Retrieving the current signal measurements and then, preprocessing them through the wavelet transform and decision tree was applied in [7] to identify the fault. In such methods, usually it is hard to select correct wavelets for specific mode. Another data mining-based differential protection method, which makes use of discrete fourier transform (DFT) to extract differential features was presented in [8]. These features are then used to build a decision tree for assessing the fault status. Other data-oriented methods such as, support vector machine [9], neural network [10], adaptive neuro-fuzzy inference system with artificial neural network-based [11] methods have also been used by the researchers to identify the fault by taking or transforming features as an input, and making out a decision regarding the status of the system.

Within the context of phasor measurement unit (PMU)-based fault detection, following works discuss about the possibility to identify the faults for ADNs by means of PMU e.g. [12]–[17].