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A statistics-based review on island detection methods in microgrids: Overall investigation and state-of-the-art

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REVIEW PAPER

ABSTRACT

In this paper, a comprehensive statistics-based review of islanding detection methods (IDMs) in microgrids (MGs) is presented. Islanding detection is the situation of isolating the MG from the main grid whether programmed as a result of load managing purposes or un-programmed due to the occurrence of faults. Islanding detection is a vital issue in MG's analyses due to the prevention of subsequent protection problems in the power system. In other words, when the MG's operation mode changes, the current passing through the protective devices changes subsequently and the protection system should be able to adapt the new settings to the protective devices. So, IDMs are vital for electrical engineers to overcome the abovementioned protection issue. This review paper surveys the existing literature in IDMs by concentration on total publications, type of publications (journal, conference paper, or book), five authors with the highest number of publications (including the affiliations), and five most published sources. Also, the five most cited publications and state-of-the-art IDMs are investigated in detail, utilizing some known and novel categorizations. This paper will be useful for the MG's researchers to know the most desirable IDMs, especially in recent years, and provides an insightful overview for future studies.

KEYWORDS

islanding detection method, protection, active, passive, hybrid, phasor measurement-based, non-phasor measurement-based, mathematics-based, artificial intelligence-based, network modelling and monitoring

1. INTRODUCTION

Microgrids (MGs) are designed as small low voltage subsections in the power systems for feeding the electrical loads. MGs are capable of working on two operation modes known as grid-connected and islanded utilizing the circuit breaker (CB) located between the main grid and MG named point of common coupling (PCC) [1]. This CB isolates the main grid from the MG. Grid-connected mode is a status in which the MG has the capability to receive the injected power from the grid [2]. On the other hand, islanding is a situation in which a section of the power system, which is separated from the main grid and includes electrical loads and distributed generations (DGs), can be supplied by the DGs. Photovoltaic (PV) units, diesel generators, energy storage systems (ESSs), and wind energy farms (WEFs) are some examples of DGs that can feed the electrical loads or transfer the surplus power to the main grid (see Fig. 1).

The power system benefits from the advantages of MGs including better system efficiency, cost reduction (due to utilizing the small-scaled DGs), improvement of power quality, and increased both power system reliability and flexibility (due to the capability of working at two operation modes) [3]. Moreover, enhancement in the stability of the power system, and reduction in global warming and pollution by the implementation of technologies with low

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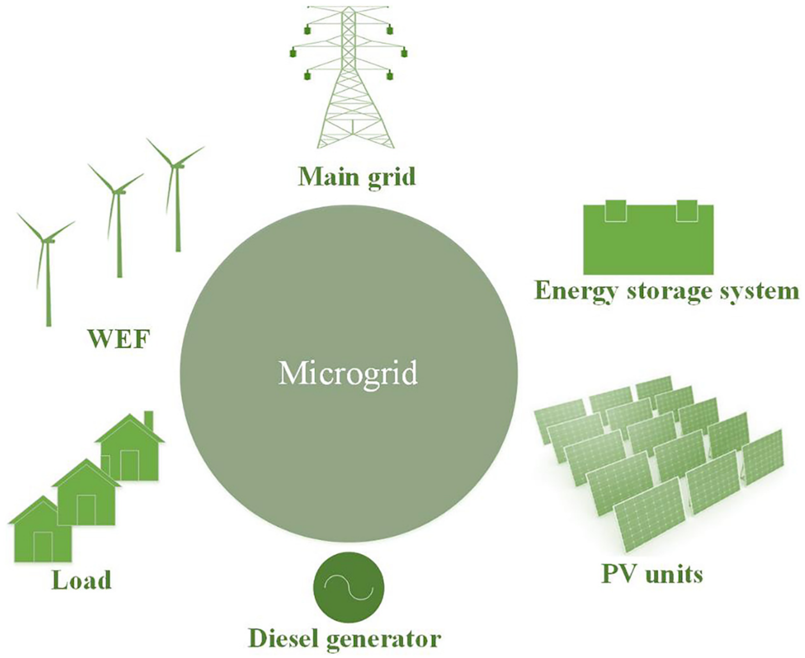

Fig. 1. The structure of a sample MG

(or without) carbon utilization can be mentioned as the significant advantages of the MGs [4]. Regardless of the abovementioned benefits, the most important issue in MGs is the detection of the islanded mode and protection actions to be adapted to this condition. In comparison to the islanded mode, the fault current is very high in the grid-connected mode, which affects the power system protection due to the significant changes in the settings of the protective relays [5, 6]. As long as a MG is connected to the main grid, if a fault occurs within the MG, a large contribution of the fault current flows from the main grid to the fault point. On the other hand, when MG separates from the main grid, this current will no longer exist and the fault current in MG is reduced. Therefore, due to the necessity of coordination among the overcurrent relays (which are the most common relays in the power system), in a MG with one group of setting for overcurrent relays, one can not expect protection with the high speed and sensitivity of the protection system that relies only on the level of fault current. Consequently, the settings of protective relays should be updated by the change in the operation mode of MG. So, there is a need for methods to detect the islanded mode and adapt the corresponding protection orders to the protective relays. These methods are known as islanding detection methods (IDMs).

Islanding mode must be detected in less than 2 s based on the standards such as IEEE 929-2000, IEEE 1547, and IEC 62116 [7]. So, islanding detection in MGs is an important issue for the control and protection of the power system. Achieving an efficient IDM with the capability of fast and accurate detection is one of the essential requirements in power systems.

In this study, a detailed investigation of existing, most cited, and state-of-the-art publications on IDMs is presented. The presented investigations will be helpful for the power system engineers and researchers to identify the most desirable IDMs.

After the introduction section, the overview of the paper is addressed in section 2. Overall statistics corresponding to islanding detection are provided in section 3. The fourth section categories the IDMs and performs a comprehensive investigation of the most cited publications and state-of-the-art methods. Finally, the fifth section presents the conclusions.

2. OVERVIEW OF THE PAPER

2.1. Database

In this paper, the bibliographic records associated with the selected issue are obtained from DOAJ, Nature Index journals, Norwegian register, VABB-SHW, UGC Journal List, China Journal Initiative, PubMed, ERIH PLUS, J-STAGE, SciELO, and ERA.

2.2. The searching procedure

As the main structure of this paper, data about the selected issue with concertation on most cited publications, and state-of-the-art methods are highlighted, and related statistical analyses are presented. The search procedure is started by the selection of keywords that are separated by the term "and" (see Fig. 2). Then, the overall investigation of the issue includes the total publications just for the last decade (i.e., 2012–2021), type of publications (journal, conference, book, or chapter), five most published authors with their affiliations along with the number of publications, and five most published sources are presented. Finally, the most cited and state-of-the-art publications of the selected issue are analyzed with some known and unique categorizations to

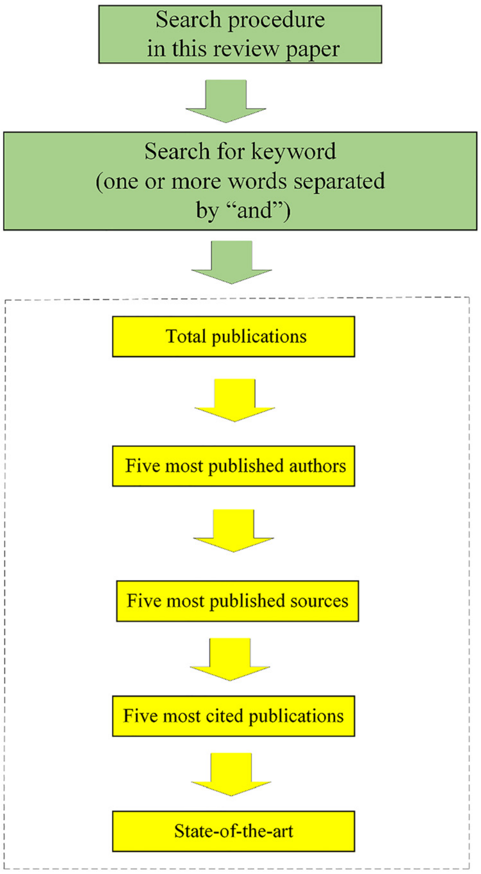

Fig. 2. The overview and the procedure of searching

obtain the concentration and concern of researchers on the selected issue.

To obtain the exact results and prevent investigating irrelevant studies, the search is applied in the title and abstract of the aforementioned databases.

3. A STATISTICS-BASED SEARCH ON ISLANDING DETECTION ISSUES

To make an accurate investigation of existing researches on IDMs, firstly, a search is performed by keyword "Microgrid and islanding detection". The statistical analyses are available in Fig. 3. It can be seen from Fig. 3(a) that 302 studies are published for islanding detection in the pre-defined period. The distributions of publications are 54% journal, 40% conference, and 5% in the type of book or chapters (see Fig. 3(b)). It is observed from Fig. 3(c), "P. Jena" from "Indian Institute of Technology Roorkee" is that the author with the most publications (i.e., 13 publications) in islanding detection issue. Also, "P. K. Dash", "V. Kumar", and "S. R. Samantaray" placed second to fourth place respectively. Moreover, "M. Biswal" with eight publications is the fifth most published author on this list. Besides, as can be seen from Fig. 3(d), "IEEE Transactions on Smart Grid", "IET Generation, Transmission & Distribution", and "Energies", with fifteen, twelve, and ten publications respectively, and "International Journal of Electrical power and Energy Systems", and "Lecture Notes in Electrical Engineering" both with nine publications stand on next stages of the five most published sources.

4. ISLAND DETECTION METHODS

4.1. Comprehensive categorizations of islanding detection methods

IDMs can be categorized into two main types: remote, and local (including active, passive, and hybrid) [8]. Remote or communication-based IDMs detect the islanding mode when the signal receiving from DGs is cut off. Therefore, regardless of the reliability and fast performance, this type of IDMs is not cost-effective due to expensive implementations [9]. Supervisory control and data acquisition (SCADA) and power line carrier (PLC) are the systems for transferring data in remote IDMs.

In the active IDMs, disturbances are injected into the power system and then the islanding mode is detected depending on the reactions of the systems [10]. These methods have a negative impact on the network's power quality and stability due to the injected disturbances [11, 12].

Some of active IDMs are Sandia frequency shift (SFS) [13], active frequency drift (AFD) [14], current disturbance injection and reactive power variation (RPV) [15], active frequency deviation with positive feedback (AFDPF) [16, 17], voltage positive feedback (VPF) [18, 19], injection of a negative-sequence current [20, 21], phase shift of current [22], virtual inductor [23], virtual capacitor [24], and slip-mode frequency shift (SMS) [25].

On the other hand, in passive IDMs, a parameter (or some parameters) of the system is considered as an index and is analyzed by determining the threshold value. If the desired parameter exceeds the value of the pre-determined threshold, the system is in islanded mode [26].

Despite, no effect on the power quality, passive IDMs suffer from the high computational burden. Moreover, running numerous simulations to identify the appropriate threshold value of islanding mode, and having large non-detection zones (NDZs) are some of the disadvantages of passive IDMs [26].

Some of the passive IDMs are under or over voltage [27, 28], rate of change of frequency (ROCOF) [29, 30], rate of change of reactive power [31], voltage signal [32–35], rate of change of positive and negative sequence of current [36], impedance monitoring [37], and total harmonic distortion (THD) [38]. Also, there are some passive IDMs that utilize two parameters of the network for decision-making such as the average rate of change of reactive power and load shift [39], rate of changes of voltage to frequency [40, 41], frequency and voltage [42, 43], current and voltage [44], harmonics and voltage [45], and power and voltage [46, 47]. Moreover, some studies utilized the monitoring and analysis of three or more parameters of the network such as the relationship of the load on frequency and voltage [48],

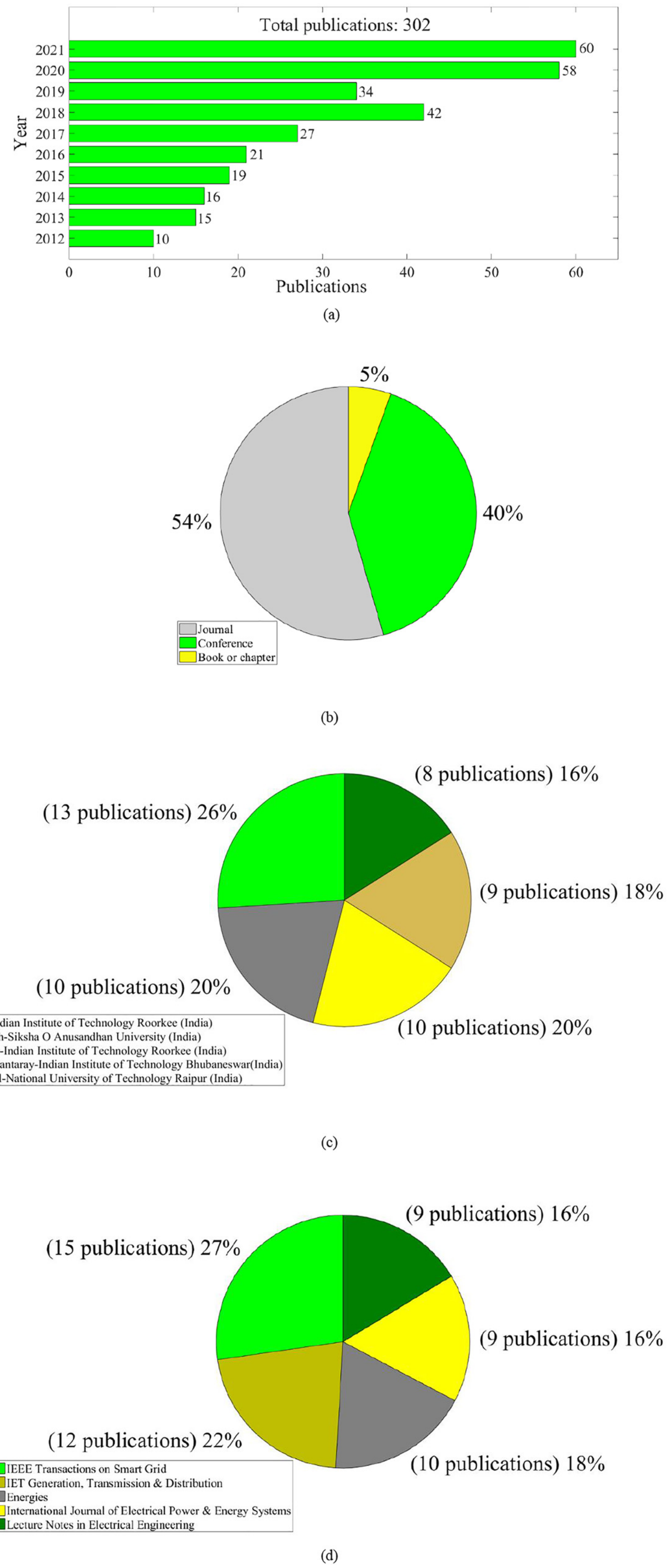

Fig. 3. The search of the keyword “Microgrid and islanding detection” (a) Total publications (b) Publications type (c) Five most published authors (d) Five most published sources

and under or overvoltage, under or over frequency, and phase jump [49].

The hybrid IDMs integrate the passive and active methods, which increase the accuracy of detection, overcome the drawbacks of both passive and active IDMs, improve the islanding detection capability, and reduce the NDZ [50].

As an example of hybrid IDMs, there is a study in which first the perturbation is injected (as the active mode) and then, active power, voltage harmonics, current harmonics, reactive power, and the rates of change of frequency are measured (as the passive mode) for final decision-making about islanding or non-islanding mode [51]. Also, in [52] a hybrid method is proposed that employs voltage unbalance (VU) (as the passive mode) and changes in the voltage phase angle (VPA) as noise (as the active mode). Moreover, in [53], a hybrid IDM is proposed that is based on the injection of the current disturbance (as the active mode), and monitoring the under or over voltage (as the passive mode). In another hybrid IDM, the connection of a reactive impedance at PCC is considered as the active mode and the measurement of the rate of change of voltage (ROCOV) is considered as the passive mode [54].

As the other categorization, the IDMs can be divided into artificial intelligence (AI)-based methods including fuzzy inference system (FIS), decision tree (DT), support vector machine (SVM), artificial neural network (ANN), etc., and as the second type, the mathematics-based methods including Fourier transform (FT), S-transform (ST), wavelet transform (WT), Sparse correlation, etc. Mathematics is used in some IDMs for extracting the features from the parameters of the network for subsequent detection purposes. The mathematics-based IDMs give reliable results but as a disadvantage, the computational burden is high. On the other hand, the AI-based IDMs regardless of the acceptable results suffer from complexity and time-consuming procedures for training data. It is to be mentioned that there are some IDMs that are just based on monitoring the behaviour of the parameters of the network and the final decision is just taken based on the modelling of the network.

Moreover, as a novel categorization, the IDMs can be divided into phasor measurement-based and non-phasor measurement-based methods. In phasor measurement-based type the angle of the network's parameters such as active power, voltage, current, and reactive power are utilized in analyses for decision-making. On the other hand, in the non-phasor measurement-based type, the amplitude of the network's parameters is used for islanding detection purposes. The drawback of non-phasor measurement-based IDMs is the high computational burden to decide about islanding or non-islanding conditions. On the other hand, the phasor-measurement-based type is fast and accurate but suffers from complexity in analyzing data and expensive devices for the sampling of the phasor data.

A comprehensive comparison between the above-mentioned categorizations of IDMs is given in Table 1.

4.2. Most cited papers on islanding detection issue

Investigation of most cited researches helps the researchers to identify the technique that is most applicable and desirable on a special issue. References [55–59] are the five most cited papers in the IDM issue (see Fig. 4).

Table 1. Comparison between the IDMs types

IDMs	Characteristic			
	Less computational burden	No need for training data	Cost-effective	Less complexity
Non-phasor measurement-based	✗	–	✓	✓
Phasor measurement-based	✓	–	✗	✗
AI-based	✓	✗	–	✗
Mathematics-based	✗	✓	–	✓

✓: In accord with the characteristic ✗: Not in accord with the characteristic.

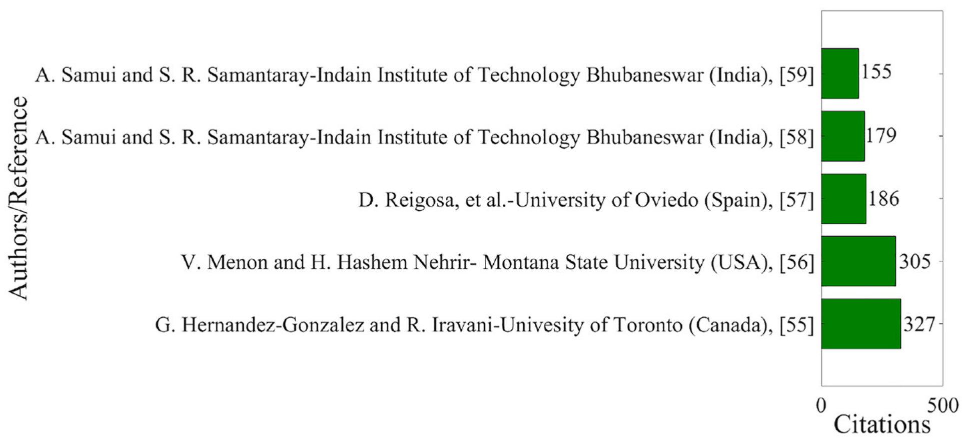

Fig. 4. Five most cited papers for IDMs

Table 2. State-of-the-art publications related to IDMs

Authors/Reference	Country	Active/ Passive/ Hybrid	Intelligence-based/ Mathematics-based/ Both//Network modelling and monitoring	Detection tool	Phasor measurement-based/Non-phasor measuremet-based	Network parameter/Technique	Detection time (ms)	Accuracy (%)
Y. A. Elshrief et al., [60]	Egypt	PIDM	NMM	–	NPH	Rate of change of power based on the terminal voltage (ROCOP-TV)	8	NM
M. Karimi et al., [61]	Finland	PIDM	NMM	–	PH	Voltage and current phasors	Less than 2000	NM
S. Barczentewicz et al., [62]	Poland	PIDM	NMM	–	NPH	Voltage amplitude, frequency, and rate of change of frequency (ROCOF)	Less than 300	NM
R. Bakhshi-Jafarabadi and M. Popov, [63]	Iran	HIDM	NMM	–	NPH	Inject the disturbance into the voltage source as the active mode, measure the drop of voltage at PCC and active power as the passive mode	300	NM
E. N. Prasad and P. K. Dash, [64]	India	PIDM	MA & AI	Detrended fluctuation analysis (DFA), adaptive variational mode decomposition (AVMD), and improved particle swarm optimization (IPSO)	NPH	Current signals	NM	97.33–99.33
N. V. Eluri et al., [65]	India	PIDM	MA & AI	Variational mode decomposition (VMD), and weighted kurtosis index, and modified particle swarm optimization (MPSO)	NPH	Voltage and current	36 and 42	99
M. Seyedi et al., [66]	Iran	HIDM	NMM	–	NPH	Rate of change of voltage (ROCOV) as the passive mode, and rate of change of active power (ROCOAP) as the active mode	2013–2042	NM
Q. Huang et al., [67]	China	AIDM	NMM	–	NPH	Voltage positive feedback of selected frequency (VPFOSF)	1,351	NM
A. Shukla et al., [68]	India	PIDM	MA	Fortescue transform (FTT)	PH	Angle difference between positive and negative sequence components/phase angle of voltage	10	NM
A. Damanjani et al., [69]	Iran	PIDM	AI	Fuzzy c-means (FCM) clustering	NPH	Fault current level	20	NM
S. K. Singh et al., [70]	India	HIDM	NMM	–	NPH	Disturbance (load change) as the active mode , and voltage unbalance and rate of change of frequency (ROCOF) as the passive mode	22	NM
L. Ma et al., [71]	China	AIDM	NMM	–	NPH	Voltage/Active frequency drift with positive feedback (AFDPF)	60	NM
P. P. Tikar et al., [72]	India	PIDM	MA & AI	Discrete wavelet transform (DWT), K-nearest neighbor (KNN), and support vector machine (SVM)	NPH	Voltage and current	120–150	95.23–100
R. Zamani et al., [73]	Iran	PIDM	MA	Hilbert-Huang transform (HHT)	NPH	Oscillation of frequency	370–450	NM

(continued)

Table 2. Continued

Authors/Reference	Country	Active/ Passive/ Hybrid	Intelligence-based/ Mathematics-based/ Both//Network modelling and monitoring	Detection tool	Phasor measurement-based/Non-phasor measuremet-based	Network parameter/Technique	Detection time (ms)	Accuracy (%)
X. Xie et al., [74]	China	PIDM	NMM	–	PH	Rate of change of power factor angle (RCPFA) and rate of change of frequency (ROCOF)	68	NM
A. Ezzat et al., [75]	Egypt	PIDM	MA & AI	Discrete Fourier transform (DFT), and K-nearest neighbor (KNN)	NPH	Voltage and current	5–15	99.69
M. Mohiti et al., [76]	Iran	HIDM	NMM	–	NPH	Injection of voltage as the active mode, and monitoring the total harmonic distortion (THD) as the passive mode	1,000	NM
O. A.Allan and W. G. Morsi, [77]	Canada	PIDM	MA & AI	Continuous wavelet transform (CWT), and convolution neural network (CNN)	NPH	Voltage and current	210	98.6
R. Bakhshi-Jafarabadi et al., [78]	Iran	HIDM	NMM	Maximum power point tracking (MPPT)	NPH	Voltage deviation as the passive mode, and disturnabce voltage as the active mode	137	NM
A. Serrano-Fontova et al., [79]	Spain	HIDM	MA	State variable	NPH	Voltage and rate of change of frequency as the passive mode, and switching the load as the active mode	120	NM
H. Khosravi et al., [80]	Iran	PIDM	NMM	Swing equation	NPH	Voltage and current/Rate of change of kinetic energy over reactive power (ROCOKORP)	50–58.3	99.28
S. V. Kulkarni et al., [81]	India	AIDM	NMM	Park synchronous reference frame based phase-locked loop (PSRF-PLL)	PH	Active power, reactive power, frequency, voltage, and grid phase angle response	10	NM
A. Kumar et al., [82]	India	AIDM	NMM	–	NPH	Frequency/Estimation of signal parameter via rotational invariance technique (ESPRIT)	120	NM
R. Nale et al., [83]	India	PIDM	NMM	–	PH	Voltage and current/Phase angle difference information of superimposed impedance	Less than 2,000	NM
A. K. Özcanlı and M. Baysal, [84]	Turkey	PIDM	AI	–	NPH	Voltage and current / Multi-long short-term memory (LSTM) architecture	50	97.93

AIDM: Active IDM
PIDM: Passive IDM
HIDM: Hybrid IDM
AI: AI-based
MA: Mathematics-based
PH: Phasor measurement-based
NPH: Non-phasor measurement-based
NMM: Network modelling and monitoring
NM: Not mentioned

Reference [55] by “G. Hernandez-Gonzalez” and “R. Iravani” from “University of Toronto” is cited 327 times. It is an active IDM (since the injection of current disturbance), and utilized the amplitude of voltage (i.e., non-phasor measurement-based) for detection purposes. Also, it is based on network modelling and monitoring.

Reference [56], with 305 citations is a hybrid, non-phasor measurement-based IDM that utilized positive feedback as the active mode and subsequently, THD and VU as the passive mode.

The third one is reference [57] with 186 citations that is an active IDM based on measurements of impedance after injection of the voltage (i.e., non-phasor measurement-based).

Reference [58] as the fourth most cited paper with 179 citations utilized the rate of change of phase angle difference of current and voltage signals (i.e., passive and phasor measurement-based IDM) along with network modelling and monitoring for detection purposes.

Finally, reference [59] that is a passive IDM based on WT technique (i.e., mathematics-based) and voltage signal (i.e., non-phasor measurement-based) is known as the fifth most cited paper.

It can be concluded that among the most cited papers, hybrid methods are the least desirable among the researchers, and network modeling and monitoring technique with non-phasor data are the most desirable categories among the IDMs. Moreover, it is remarkable that the most cited papers were published from 2006 to 2012.

4.3. State-of-the-art island detection methods

Investigation of state-of-the-art methods helps the researchers to find the recent approaches in the special field and make an insightful overview for future directions of the issue. So, considering the aforementioned definitions for categorizations related to IDMs, a comprehensive search of state-of-the-art IDMs is given in Table 2. It is to be noted that only the “original research” papers are utilized to be investigated as state-of-the-art IDMs in Table 2. Moreover, authors with the corresponding country, detection tool, technique or network’s parameter, detection time, and accuracy of the researches are highlighted in Table 2.

As presented in Table 2, most IDMs are focused on detection time rather than accuracy which illustrates the significance of quick detection to perform subsequent proper protection actions. Also, the ranges in the “detection time” column indicate the different scenarios or cases. Moreover, reference [72] provided the most accurate IDM among the recent studies, and the proposed methods in references [60], [68], [69], [75], and [81] are reported to detect the islanded mode within 20 ms that can be known as fast detection IDMs.

Also, according to the results that are given in Table 2, the concentrations of recent IDMs are on passive methods (see Fig. 5(a)). Furthermore, 60% of the recent IDMs are

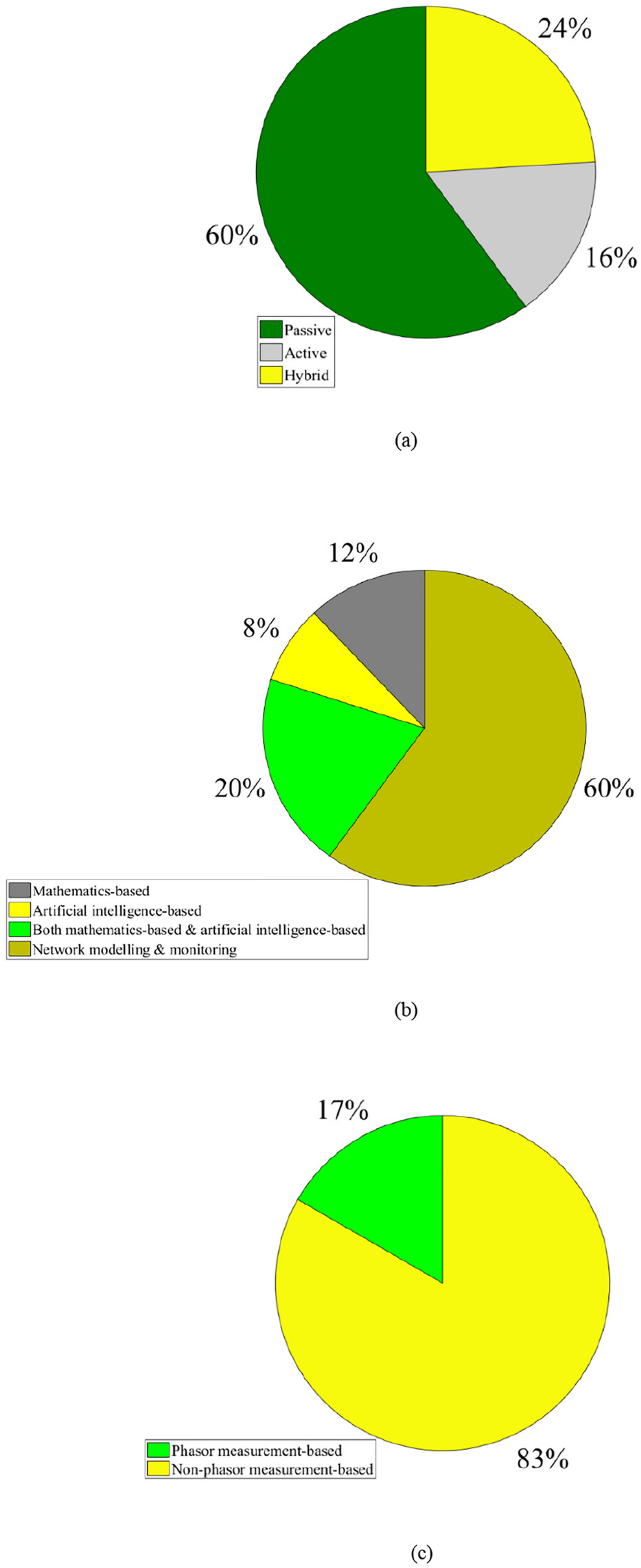

Fig. 5. Categorizations contribution on state-of-the-art IDMS (a) Type of method (b) Detection tool (c) Usage/not usage of phasor measurements data

specialized to network modelling and monitoring procedures (see Fig. 5(b)). Moreover, the combination of both mathematics-based methods and artificial intelligence-based methods contributes 20% of the methods that shows the researchers' desire in using AI tools along with mathematics techniques (see Fig. 5(b)).

In addition, due to the expensive implementation and complexity of phasor measurement-based IDMs, non-phasor measurement-based IDMs are utilized more for detection purposes (see Fig. 5(c)).

Finally, it can be concluded from Table 2, among the recent studies on IDMs, India, and Iran totally with more than 50% of publications play a vital role in publishing the research papers among the other countries.

5. CONCLUSIONS

In this study, a review of IDMs is presented that is based on statistics obtained from known databases. Considering the known categorizations (i.e., active, passive, hybrid, AI-based, and mathematics-based), and a novel categorization (i.e., phasor/non-phasor measurement-based), a detailed investigation of the most cited methods and state-of-the-art IDMs is performed. According to the analyses, most of the researches both on most cited and recent studies on IDMs utilized network modelling and monitoring for detection purposes. Besides, among state-of-the-art IDMs, it can be concluded that most of the researchers tend to retain the power quality by providing more passive methods. Moreover, it is illustrated that the researchers tend to reduce the complexity and cost in recent studies by utilization of non-phasor data. The findings of this review paper are essential and practical for the researchers of MG issue and especially for the electrical engineers of the power system, for future programming and improvement of the protection system.

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