

Droop Inverter Control Technique in AC Microgrid-A Scientrometric Study

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Abstract—A considerable amount of clarification and control are required whenever integrating multiple distributed generation (DG) systems into the power system, as DG systems are becoming increasingly together in the grid. Flexible and reliable control strategy and management concept of interconnected systems are needed to handle different types of distributed generation. The main objectives that each distributed generation controller and the Microgrid controllers should pursue in both grid-connected and island-mode operations are discussed in this paper, along with the components and structure of the Microgrid. The difficulties of having multiple distributed generating units in a Microgrid are also highlighted. Such as accurate power sharing and control, voltage and frequency regulation, power management between distributed generations, installation and integration of different renewable energy sources, smooth mode transition, and modeling issues. First, to analyze and contrast them as workable options, both centralized and decentralized control systems have been highlighted. Moreover, recent studies have determined the primary solutions. and Control techniques for Microgrids with drooping alternating current. Bibliography analysis provided a comprehensive evaluation of droop inverter control techniques in ac Micro grids.

Index Terms— Distributed generation (DG), Droop control inverters, Micro grid (MG), Parallel operation, Smart grid.

I. INTRODUCTION

Power systems are adopting a new plan with a large number of reduced-scale systems called micro grids (MGs), connected by networks of intricate transmission lines whose nodes have a high degree of intelligence, as a result of distributed generation and smart grids. At the distribution line level, the MGs might be connected to one another. Each self-sufficient micro grid (MG) has energy storage, distribution lines, loads, and interfaces with the Common Coupling Point, a higher-level grid. This higher-level grid is called a micro grid. The MG operates at low and medium voltages. Such a way of operating is called "islanding" Examples of CCP including protective gear, intelligent equipment with communication capabilities, and line-frequency transformers. This method has a number of advantages. Actually, it improves system resilience by lowering gearbox losses, raising efficiency, providing active load control, isolating MGs from outside disturbances, failures, and outages, and streamlining self-healing because of its high degree of modularity and local energy consumption. The concept can also be used to wind farms or other such systems, as the majority of an MG's components are generators; nonetheless, the quantity of energy produced in an MG often meets local consumption.

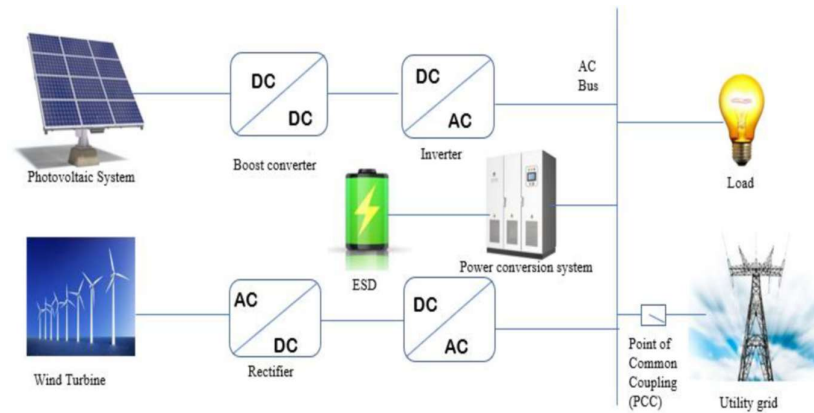


Fig.1. Basic Micro grid Architecture [6]

To obtain energy produced in other MGs, distribute energy, or satisfy peak demands that cannot be satisfied locally, higher hierarchical-level links are built.

In order to counteract the drawbacks of renewable energy sources (RESs), such as daily swings in energy prices, RESs are paired with fuel-based generators, typically TG, which are subsequently supplied by biomass or CHP systems. Fuel cells may someday replace integrated thermal power plants, despite the fact that they are now unaffordable. For inverter-based control in AC micro grids, droop control

is a popular technique that provides dependable operation without requiring complex communication networks. Droop control techniques have been shown in numerous studies to be an effective means of controlling voltage, frequency (F), active power (P), and reactive power (Q) in micro grid systems. Proper and exact power sharing among distributed producers is one of these approaches that enable the seamless integration of different energy sources while meeting load requirements in islanded or grid-connected modes. Droop control facilitates the parallel operation of distributed inverters, providing a dependable means of maintaining system performance and stability under a range of operational conditions. Ultimately, droop control is a well-proven technique for effective inverter-based control in AC micro grids.

Current research on droop-control inverter systems for AC micro grids is looking into a number of strategies to increase power sharing, stability, and operational efficiency. Toub et al. (2019) use their novel dq droop control technology to demonstrate power-sharing without frequency distortion while maintaining fixed operation in AC micro grids. The droop-free hierarchical control technique proposed by Rey et al. (2020) addresses power sharing, frequency regulation, and voltage regulation even in the presence of unfavourable conditions such as communication barriers. By utilising mixed-integer conic programming to improve droop parameters economically, Jabr (2022) made significant advancements in the field of voltage stability and cost-effectiveness (Jabr, 2022). Instead of relying on prior knowledge of feeder impedances, Mohammed et al. (2023) developed a strategy that improved reactive power sharing and reliability in islanded microgrids by accounting for mismatched feeder impedances. Ling and colleagues (2020) introduced a dispatchable droop control method that combines active and reactive power regulation with voltage and frequency management, making it flexible enough to adjust to unfeasible power-control benchmarks. Using an adaptive neuro-fuzzy inference system and PID controllers for power management, Prasad et al. (2022) produced a demonstration of the effectiveness of the autonomous droop control technique with an emphasis on hybrid AC/DC microgrids.

In summary, there is a wide range of research being done on droop-control inverter techniques for AC microgrids. Research is concentrated on three key areas: sustaining fixed-frequency operation, optimising control strategies for stable and cost-effective performance, and guaranteeing dependable power sharing under a variety of operational obstacles.

II. LITERATURE SURVEY

Reference [1]-The primary focus of the study article is the stability of synchronised motions of inverter-based microgrids under droop management.

- The passivity-based control technique based on interconnection and damping assignment is used to depict the lossless microgrid in port-Hamiltonian form. This makes it possible to determine the energy

- Lyapunov function and the conditions that must be met for the synchronisation equilibrium state to remain stable.
- In Section 2, the study explains the network model; in Section 3, it discusses the inverter model and droop management; and in Section 4, it lays out the requirements for local stability for lossless microgrids.
- To guarantee that distributed generation units distribute active power in accordance with a predetermined pattern, it also suggests a choice of droop gains and setpoints in Section 5
- In Section 6, simulations based on the CIGRE benchmark medium voltage distribution network are used to assess how resilient the stability conditions are with respect to model uncertainties, such as conductances.
- Reference [2]-The significance of inverters in microgrid systems for transforming DC electricity from renewable sources into AC power for distribution is covered in the study.
- It draws attention to how ineffective conventional droop control
 - techniques are at producing a balanced reactive power distribution in MGs. Various control modes, including voltage-source and current-source, are used in accordance with operational needs; grid-connected new energy generation is more likely to use the current-source mode.
- To overcome the drawbacks of conventional control approaches, the paper suggests a dynamic droop coefficient control strategy reinforced with deep reinforcement learning to optimise inverter performance under varied situations.
- The technique shows better performance than previous systems by using deep deterministic policy gradient to prevent unequal reactive power distribution without voltage drop.
- Reference [5]-This work focuses on the design and optimisation of parameters for droop-controlled inverters (DCIs) to ensure optimal performance in supporting the utility grid with active and reactive power.
- The construction of equivalent output impedance and admittance models for DCIs is covered, along with an analysis of how different factors affect power stability and impedance characteristics.
- To make the process of parameter tuning for DCIs easier, the study suggests a generic parameter design outline with a thorough tuning methodology based on the findings of impedance analysis.
- To confirm the viability of the suggested parameter design and optimisation approach, a 15 kVA prototype is built and tested in a lab.
- In addition, the research explores the resonant frequency of LCL filters and the output voltage error signal, taking resonance and proportional coefficients into account for high-quality power regulation.
- The usefulness of the equivalent sequence impedance model for analysis is highlighted by mentioning the importance of power loop parameters in connection to the risk of Subsynchronous Resonance (SFR) and the small-signal stability of DCIs.

III. METHODOLOGY OF DISTRIBUTED GENERATION OPERATION

Although the inverter-based Micro grid can work as a standalone system in island mode, the Power converters [1]-[3] are classified into 3 control classes as follows:

A. Grid-Forming Units

In this category, the DG is designed for autonomous operation and, as Fig.5 shows, is an ideal source of AC power with a constant output frequency. For stable values and strong disturbance rejection, a closed-loop controller is incorporated. During Micro grid island mode operation, grid-forming units balance the needs of load and generation power to control the voltage and frequency of the system. However, the grid-forming units are modified to function as grid-feeding units in the grid-connected operation mode [7], since there are frequency and voltage references from the primary grid. Thus, to guarantee smooth transients during the micro grid mode switches, the control strategies for grid-forming units should be appropriate for both micro grid operation modes.

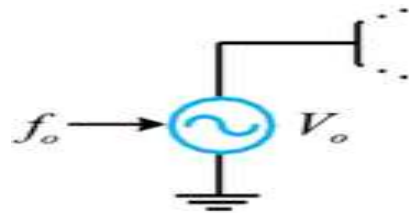


Fig. 2. Grid-forming units [7]

B. Grid Feeding Units

This DG is intended to regulate the output power or current, which, as seen in Fig.6, is synchronized in frequency with the main AC bus, thus serving as an ideal current source. It has little effect on power balancing in microgrids.

The primary application of this control technique is in the grid-connected mode for PV and wind integration applications. Since the output voltage (V_0) is fixed by the grid or another forming unit, it is not an objective in this case.

C. Grid Support Units

In all Microgrid operating modes, power sharing and management are made possible by the controlled voltage source (DG), which is engineered to regulate both its output voltage and frequency. The voltage (V) and frequency (f) of the voltage source are subject to the necessary active and reactive output power and are no longer fixed, as shown in Fig.7. This class can also function as a source of current or voltage, depending on the control system that is used. It combines the capabilities of grid-forming and grid-feeding devices to provide smooth operation switching and transfer.

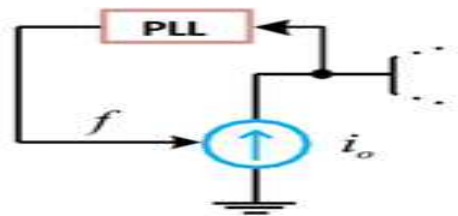


Fig.3. Grid feeding unit [7]

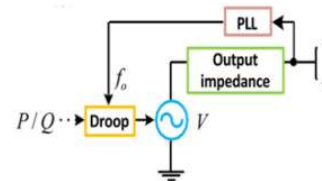


Fig.4. Grid support unit [7]

Alternatively, DGs can be categorized as voltage- or power-controlled sources (PCSs) in the literature in the following ways:

- The voltage-controlled source (VCS) can be used to build a grid by controlling its voltage and frequency, or it can be used to adjust its voltage and frequency for power sharing and balancing. It is a grid-supporting unit here. This operating mode, where V and f are set internally, is also known as V/f mode.
- The PCS regulates the output power (P_0) and current, whereas the grid or another forming/supporting unit regulates the bus. The P/Q mode is another name for this mode. The power set points for controlled energy sources, such as fuel cells and micro-turbines, are supplied by the MGCC. But for RES'S like solar and wind, the power set points are determined.

D. A distribution line with multiple distributed generation (DG) units in a micro grid can bring several challenges:

- Coordination and control: Complex control procedures are needed in order to synchronize the operation of several distributed Generation units in the microgrid. The stability and dependability of the system depends on each component working together.
- Voltage and frequency regulation: Varying the voltage and frequency within the Micro grid due to several DG units is possible, particularly in temporary situations. The stability and dependability of the system depends on each component working together.
- Islanding detection: Avoiding equipment damage and safety hazards when a Micro grid is operating in islanded mode, or detached from the main grid, requires prompt identification of islanding occurrences. Coordinating the activities of many DG units to identify islanding might be challenging
- Synchronisation: Exact control is required to synchronise multiple distributed generation units (DG) with the main grid and, if connected, with one another, in order to ensure smooth transitions.
- Load sharing: Distributing the load among multiple dispersed generation units while ensuring fair distribution of the load can be challenging, especially if the units have different capacities or characteristics.
- Communication and Data Exchange: To enable control and monitoring, coordinating the actions of several DG units and transmitting real-time data efficient communication networks.
- Fault Management: It is necessary to promptly identify and isolate Micro grid defects, such as short circuits or equipment failures, to stop cascading failures. The reliability of the system depends on the coordination of the reactions of several DG units to malfunctions.

IV. DECENTRALIZED AND CENTRALIZED POWER MANAGEMENT IN MICROGRIDS

In micro grids, decentralised power management refers to the application of control methods where scattered terminals autonomously determine what to do based on local data. Decentralised power management in DC micro grids makes it possible to share power autonomously among several sources by utilising different strategies like voltage/current or voltage/power droop control schemes. For efficient power balance and stability, the mode-adaptive control framework divides converters into power and voltage terminals. This enables micro grids to change their operation modes in response to changing circumstances without the need for outside dispatching. This boosts dependability and adaptability even more. Improved droop control strategies are also necessary for micro grids to maintain power balance and control voltage levels. For example, cooperative algorithms and adaptive droop resistance enhance load sharing and voltage regulation. Reducing power intermittency and unpredictability in micro grid operations while providing a stable, predictable, and affordable power supply is the aim of these solutions. Decentralised control systems play a crucial role in micro grid administration due to their dependability and flexibility. Various strategies, such as voltage/current or voltage/power droop control schemes, are commonly used for autonomous power sharing in DC micro grids. These solutions aim to address issues with load sharing, voltage management, and power quality in order to guarantee the micro grid runs efficiently and profitably. Furthermore, more advanced droop control algorithms have been developed to support system stability, effective load management, and an increase in the accuracy of power-sharing across distributed generators. Furthermore, deep reinforcement learning algorithms have been proposed as a way to dynamically optimise droop control coefficients, eliminating uneven reactive power distribution in microgrids without resulting in voltage drop. Collectively, these diverse approaches highlight the significance of decentralised control strategies in enhancing the performance and reliability of microgrid systems.

Both centralised and decentralised control mechanisms are used in microgrid systems. Even in cases where communication-based regulation by an energy control centre is involved, centralised control may not be scalable or dependable enough for large systems. Conversely, decentralised control boosts dependability and flexibility by allowing scattered endpoints to make their own decisions in response to local inputs. Voltage/current or voltage/power droop control techniques are commonly employed in the context of DC microgrids for decentralised power management to provide autonomous power sharing among many sources. Furthermore, it has been proposed that a mode-adaptive power management system can increase flexibility and stability by adapting microgrid operation modes to the dc voltage level without requiring external dispatching. Effective coordination of distributed energy resources is the goal of these solutions, which aim to offer microgrid systems with a consistent, low-cost powersource.

V. CONTROL OF POWER CONVERTERS FOR DG SYSTEMS OF THE GRID

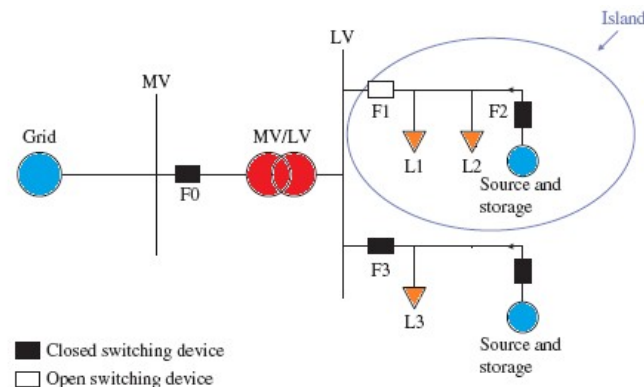


Fig.5. Basic operation of Microgrid [25]

Grid-interactive microgrids [4] are becoming an increasingly attractive structure for the proposal of an active distribution grid. A Microgrid can be conceived as a cluster of interconnected DGS load and energy storage units coordinated to be treated collectively as a single controllable device [4,5]. A preliminary evaluation of the general structure of a single DGS unit has been provided in previous sections, and the main control issues have been investigated. Therefore, the focus is on the problem of power management of DGS, which represents the

key point toward a 'universal' operation of DGS. The goal is to allow the DPGS operation in the case of stand-alone, grid-connected, and microgrid conditions by managing the disconnection and reconnection without substantial changes of the system control structure. The basic Microgrid architecture is shown in Fig.1, in which the components can be physically close to each other or distributed geographically, and where the loads may be critical or non-critical. Critical loads require reliable energy sources and require stringent power quality. Grid-connected operation, the static transfer switch (STS) is closed, and each DGS unit generates fixed active and reactive powers, according to the dispatched references, or the tracking of the maximum power that can be extracted from the source. In the case of a stand-alone operation, DGS units should supply loads that provide power sharing according to the respective ratings and achieve power balance between production and consumption. To date, DGS power converters are required to change their control structure with respect to grid-connected operation and stand-alone operation because, in the past, DGSs were conceived as current source devices in the first case and as voltage source devices in the second. In this hypothesis, a current control loop is present in both cases, but for a stand-alone operation, the voltage across the capacitor of the grid filter might also be controlled. The voltage control can offer a good trade-off performance in all operating modes. In particular, in grid-connected operation, the voltage control allows strict regulation of the voltage at the PCC and support of the voltage applied to the local loads in the case of voltage sags. In the cases of standalone and microgrid operating modes, the power converter control is only responsible for voltage regulation, because the grid is absent and the control system may guarantee high performance in terms of voltage profile and fast recovery in the case of load transients. Therefore, the appropriate functioning of the microgrid under all operating conditions requires accurate power flow management and the implementation of voltage regulation algorithms. Two control approaches can be followed to realize the above-mentioned objective, which are non-communication-based control and communication-based control. Communication-based control of a Microgrid relies on the exchange of control information among the different DGSs. This technique requires a centralized microgrid controller, which receives information from each DGS and loads the DGS units at different load conditions. There are many drawbacks to the communication-based approach. The high-bandwidth communication infrastructure necessary to share the dynamic sharing information is an impractical and costly solution in microgrids with long connection distances between inverters, and the need to distribute control signals reduces the reliability of the microgrid system, where the control information is critical for proper operation of the DGSs. Ideally, there should be no communication connections between the control algorithms implemented in the parallel DGSs. Only feedback variables that are measurable locally should be used in the control algorithms of each unique DGS [1]. By using the frequency and voltage droop method, a straightforward non-communication based power regulation can be implemented. The power theory is the source of this idea, according to which a grid-connected generator will decrease its frequency as the amount of power needed grows. Each DGS shares the active power by drooping the voltage frequency according to the total load demand in a manner determined by its frequency droop characteristic, and essentially utilizes the voltage frequency as a communication link between the DGS control systems. Similarly, a drop in the magnitude of the voltage with the reactive power is used to ensure the sharing of reactive power. This control technique is called the 'droop method'.

VI. DROOP CONTROL METHOD:

Fig.1, shows a Microgrid composed of different types of resource, such as solar panels, fuel cells, and wind turbines. Every unit has an inverter as an interface connected to the common bus through a cable that can be modeled as impedance, as shown in Fig.5.

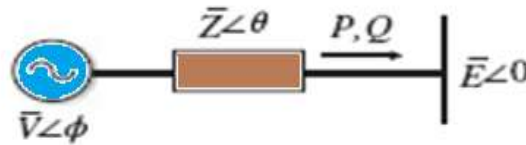


Fig.6. Equivalent circuit of an inverter connected to bus

Active power flow (P) and reactive power flow (Q) [7] from an inverter to the grid can be expressed as follows:

$$\text{Active power (P)} = 1/Z [(EV \cos \phi - E^2) \cos \theta + EV \sin \phi \sin \theta] \quad (1)$$

$$\text{Reactive power (Q)} = 1/Z [(EV \cos \phi - E^2) \sin \theta - EV \sin \phi \cos \theta] \quad (2)$$

Where, V is the output inverter voltage amplitude, E is the amplitude of the common bus voltage, ϕ is the converter voltage angle and Z and θ are the magnitude and phase of the output impedance, respectively.

Assuming that the output impedance is purely inductive XR , R can be neglected.

Consequently, (1) and (2) can be rewritten as follows.

$$\text{Active power (P)} = EV [\sin \phi] / X \quad (3)$$

$$\text{Reactive power (Q)} = EV [\cos \phi] / X - E^2 / X \quad (4)$$

Considering that the angle is small, then $\sin \phi \approx \phi$ and $\cos \phi \approx 1$ and thus, (3) and (4) become

$$\text{Active power (P)} \approx EV / X \phi \quad (5)$$

$$\text{Reactive power (Q)} = (E / X) (V E) \quad (6)$$

Where X is the output impedance at the fundamental frequency. From these equations, it is possible to deduce that the active power can be regulated by acting on the phase, while the reactive power can be regulated by controlling the converter voltage amplitude V .

These conclusions form the basis for droop control [23]. The droop method uses frequency instead of phase to control active power flow. This is because the DGS unit does not know the initial phase value of the PCC voltage, whereas the initial frequency at no load can be easily fixed. Therefore, the conventional droop method can be expressed as follows.

$$\omega = \omega^* - mp (P - P^*) \quad (7)$$

$$V = V^* - nq (Q - Q^*) \quad (8)$$

Where ω^* and V^* are the rated frequency and voltage, P^* and Q^* are the set points for active and reactive powers and mp and nq are the proportional coefficients. The frequency and voltage control characteristics are shown in Fig.7. The output inductance of the inverter X should be selected properly. In fact, increasing the output impedance reduces the circulating current produced by the differences between the power lines or between the DPGS parameters, such as the output filter parameters or the set point of frequency and amplitude set point. ω^*, V^*

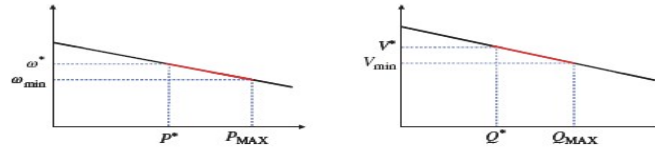


Fig.7. frequency and voltage drop characteristics [4]

As shown in Fig.8, increasing X also reduces the maximum active power (P_{max}) that can be injected,

Whereas decreasing the output impedance forces the angle ϕ to become smaller:

$$\phi = \sin^{-1}(PX / EV) \quad (9)$$

Thus, there is a trade-off in the output impedance design. In the case of a low-voltage micro grid, the line resistance cannot be neglected. In this case, the droop regulation described by and is no longer effective. Controlling the power flow based on equations and will introduce coupling and the real power(P), and the reactive power(Q) will no longer be regulated independently, but if $Z=R$ and $\theta=0$, then

$$P = E / X (V E) \quad (10)$$

$$Q = EV / X [\phi] \quad (11)$$

Hence, P and Q exchange their roles:

$$\omega = \omega^* - m'(Q - Q^*) \quad (12)$$

$$V = V^* - n' (P - P^*) \quad (13)$$

Consequently, a control scheme based on P - and Q - V droops can be used for inductive impedance, whereas P - V and Q - ω droops can be used in cases of resistive impedance. To introduce decoupling between the active and reactive powers for every line impedance condition, it is possible to use a frame transformation matrix T to modify the active and reactive powers P and Q in PC and QC :

$$\begin{bmatrix} P_c \\ Q_c \end{bmatrix} = T \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} \sin \alpha & -\cos \alpha \\ \cos \alpha & \sin \alpha \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} X/Z & -R/Z \\ R/Z & X/Z \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \quad (14)$$

$$\text{Where, } \alpha = \text{atan}(X/R) \quad (15)$$

Applying this transformation to (3) and (4) results in

$$P_c = EV X \sin \phi / Z \quad (16)$$

$$Q_c = EV [\cos \phi] / Z \quad (17)$$

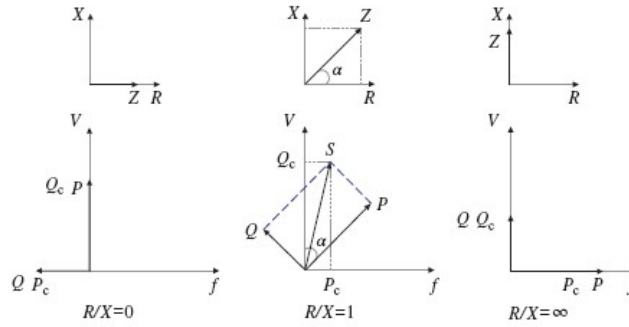


Fig.8. Influence of active and reactive powers on voltage and frequency [4] for different line impedance ratios

The definition of PC and QC allows independent influence on the frequency and amplitude of the grid (Fig.8). To obtain PC and QC , it is sufficient to know the R/X ratio, even if, unfortunately, the transformation frame depends on the accuracy of the impedance knowledge

VII. METHOD USED FOR DROOP CONTROL

Reference [1]- It represents the lossless microgrid in a structured manner by using the interconnection and damping assignment passivity-based control approach, which makes it easier to identify an energy-Lyapunov function for stability analysis.

- In order to address frequency stability, voltage stability, and power sharing in inverter-based microgrids with meshed topologies and predominantly inductive power lines, the research presents an inverter model and droop management technique.

- The study validates the use of lossless admittances, which is typical in power systems studies, to examine the stability of synchronised motions in microgrids under droop control by taking into account the inverter output admittance and ignoring resistive effects.

- The method involves establishing conditions for local stability, proposing controller parameter conditions for achieving desired active power distribution, and evaluating the robustness of stability conditions with respect to the presence of conductances through simulation examples based on a benchmark distribution network.

Reference [2]- To maximise inverter performance in microgrid systems, the study paper's methodology suggests a dynamic droop coefficient control strategy improved with deep reinforcement learning.

- The droop control approach is treated as a multi-objective optimisation problem, and a Markov decision process is developed to handle the variations in bus voltage and reactive power distributions of microgrids.

The optimisation problem is solved by applying a deep reinforcement learning technique called deep deterministic policy gradient, which yields a dynamically optimal droop coefficient control strategy.

- In order to achieve stable frequency and voltage management in microgrid inverters, the technique mimics the inherent droop characteristics of traditional synchronous generators by selecting active-frequency droop and reactive power-voltage droop. By constructing a mathematical model and utilising a deep reinforcement approach, the work solves the optimisation model, exhibiting rapid convergence and adaptability in various contexts.

- The technique chooses active-frequency droop and reactive power-voltage droop to accomplish stable frequency and voltage control in microgrid inverters by mimicking the natural droop characteristics of conventional synchronous generators.

Reference [3]- The study presents a model of the line distribution grid and the issue discussed in Section 2, with an emphasis on employing inverter-based controllers to regulate the voltage of a power distribution network.

- By reworking the distribution grid model and adding new variables, the authors reformulate the goal outlined in Section 2 and make the conclusions relevant to a variety of power distribution networks, including a benchmark low-voltage European residential network.

- The study offers verifiable assurances for employing modified droop controllers to manage customers' voltage levels within a specified range. These controllers extend the possibilities beyond traditional saturation functions by using a class of droop functions that satisfy a slope-restricted requirement. They obtain nominal voltage from the substation.

-By merely needing to know the upper limit of each customer's power generation and consumption, the adequate condition for voltage regulation protects privacy. Results on voltage regulation in a radial distribution grid employing droop controllers to control reactive power injection are presented in the paper's conclusion.

-The study, which was validated on a European low voltage residential grid benchmark model, makes use of the linear Dist-Flow model, takes the inverter's response time into account, and lets operators create a droop law to keep voltage levels within a certain bound.

Reference [4]-

- To develop and optimise settings for droop-controlled inverters (DCIs), the paper uses experimental verification in addition to theoretical analysis.

- In order to comprehend the effects of factors on impedance characteristics and power stability, theoretical study entails creating equivalent output impedance and admittance models for DCIs.

- To ensure optimal DCI performance and ease the process of fine-tuning parameters, a fundamental framework for parameter design is proposed based on the impedance analysis findings.

- The effectiveness of the proposed parameter design and optimisation technique is experimentally verified using a 15-kVA prototype in a laboratory context.

Reference [5]-

- To demonstrate the suggested control technique, the research paper uses modelling, eigenvalue analysis, control design optimisation, and time-domain simulations.

- The robust performance of the control system is ensured by the use of the Linear Quadratic Regulator (LQR) methodology in the control law design.

- In order to improve load sharing performance and lessen the detrimental effects of increased angle droop gains on stability, an additional control loop is included.

- In order to increase system stability and load sharing in microgrid systems, the study designs the gain matrix for the control law using parameter optimisation approaches.

- In order to achieve the intended output voltage for the system, the authors concentrate on the converter control strategy and ignore switching actions during the model derivation process.

VIII. SCIENTOMETRICS ANALYSIS WITH BIBLIOMETRIC:

Trend analysis is a common application of "scientometrics," a field of study that examines the numerical components of science's distribution mechanism. Citation analysis is important in academic publications, but it is not the main focus.

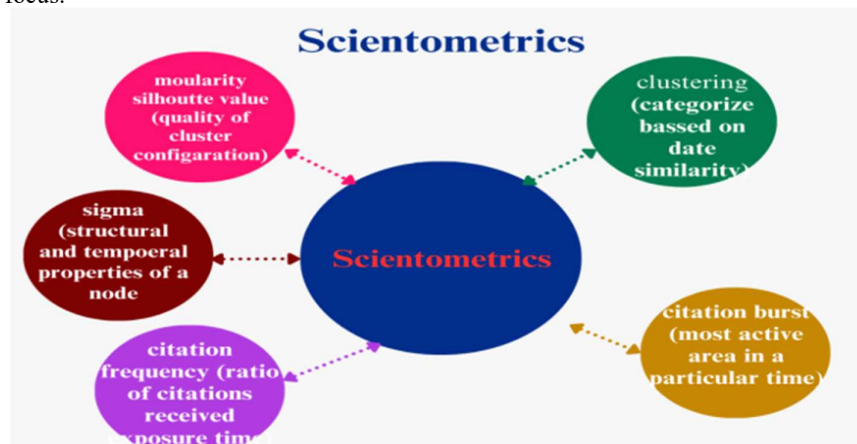


Fig. 9. Concept of Scientometrics and its Application

This synopsis takes into account the increasing importance of the metric in evaluating the efficacy of scientific research over the last many years. We cover the evolution of scientometrics, sources, citation metrics, scientometric "rules," normalisation of citation data, journal impact factors, other journal measures, research visualisation and mapping, assessment and mapping of science, and future directions. Scientometrics and bibliometrics are in crisis despite the field's rapid growth and the increasing interest in scientometric indicators; Subfields are getting farther apart from one another. and there is disagreement on.

IX. RESULTS AND DISCUSSION

A. Research Productivity

Fig.10 shows the yearly production of research in publications and citations related to the Droop inverter control technique in the AC micro grid. No citations were found for the initial paper on this topic, which was published in 2000 and 2001. The Droop inverter control technique in AC Microgrid research output has grown following the release of the first article in 2001. When 100% of the publications were created, the biggest increase was shown between 2007 and 2024. 2002 was the year with the highest number of publications 100.

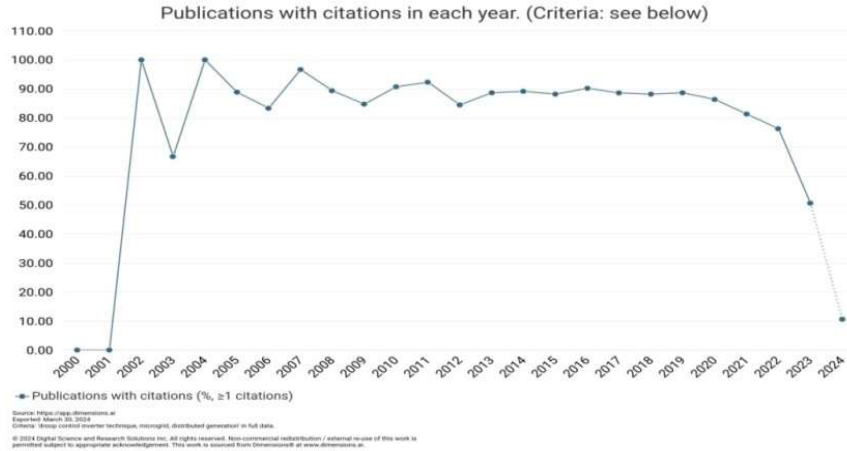


Fig.10. Publications and trends in citations in Droop inverter control technique in the AC microgrid from 2000 to 2024

Completeness of bibliographic metadata

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
AU	Author	7	0.90	Good
C1	Affiliation	10	1.29	Good
CR	Cited References	15	1.93	Good
DI	DOI	28	3.60	Good
DE	Keywords	50	6.44	Good
ID	Keywords Plus	91	11.71	Acceptable
RP	Corresponding Author	350	45.05	Poor
NR	Number of Cited References	777	100.00	Completely missing
WC	Science Categories	777	100.00	Completely missing

Fig. 11. Publications and trends in Droop inverter Control Technique in AC Micro grid

B. Publishing and Citation Structure of Droop Control Technique in AC Micro Grid

In addition, it presents the h-index, the total publications (TP), the number of cited publications (NCP), the total citations (TC), the mean citations per publication (TC/TP) and the mean citations per cited publication (TC/NCP). Between 2000 and 2024, a total of 14,735 publications were created, 374,277, and citations (or 100% of all received citations) were made during that time. With a mean of 25.40 citations per document (TC / TP), 2002 had both the largest number of documents (N = 100) and the highest number of citations (N = 100). According to publication trends, research on Droop inverter control technique in AC microgrid is growing dramatically over time. Despite the modest progress in AC microgrid research, these results indicate that the Droop inverter control technique has gained prominence in 2001 papers.

C. Leading Countries and Institutions:

Table 2 summarizes the top 10 countries and organizations in Droop inverter control technique in AC Microgrid research productivity in terms of total publications are 777, the average citations per document are 22.34% and the annual growth rate is 16.02%. The top countries with the highest number of publications included SPAIN in

terms of total publications 3710 with total citation 3394, at the bottom of the list, produced 201 publications.

Publications
From USA were cited 201 times and had a citation impact of 68.36. Despite lower volume of publication, MALASIA publications had a higher citation of 377. The USA had the lowest citations of 294 with 201 publications and 3710 citations among the top ten countries.

D. Top 10 Countries (From Scopus Data Base)

TABLE 1. LEADING COUNTRIES AND INSTITUTIONS

S.No	Country	TC	TP
1	Spain	3710	3394
2	China	1166	665
3	India	1146	608
4	Iran	513	212
5	Austrelia	499	218
6	Japan	413	338
7	Canada	419	332
8	Malasia	377	07
9	Egipt	375	192
10	USA	294	201

As far as the top 08 organizations in Droop inverter control technique in AC micro grid are concerned, Ghent University, Belgium is at the top with 03 publications and 248 citations University of British Columbia, Canada is at number two with 02 publications and 58 citations, respectively followed by the University of Tabriz, Iran (02 publications and 58 citations). The remaining six organizations got 991 citations and had the highest citation impact of 330.33. Contributed 02 publications. The Aalborg University,Denmark,

E. Authors' Analysis

The author's analysis is useful for the identification of the most relevant authors in a specific field. This type of analysis was conducted using the Biblioshiny software.

F. Author Productivity through Lotka's Law

Lotka's law describes the productivity of authors in a certain subject area. According to Lotka's law, "as the frequency of publications increases, the approximate number of authors with that frequency of publications can be predicted", and in particular, "at a higher level of productivity, there are fewer authors" Rocabert.j;luna a;blaabjerg;rodriguez. This law enables us to identify the most significant authors in a certain area. Fig.14 depicts Lotka's law, which

Computes the frequency distribution of scientific productivity, generated through Biblioshiny, which relates the percentage of authors and the number of documents published by them. It can be noticed that the percentage of authors with a lower number of articles produced is very high compared to the percentage of authors with more than three published documents.

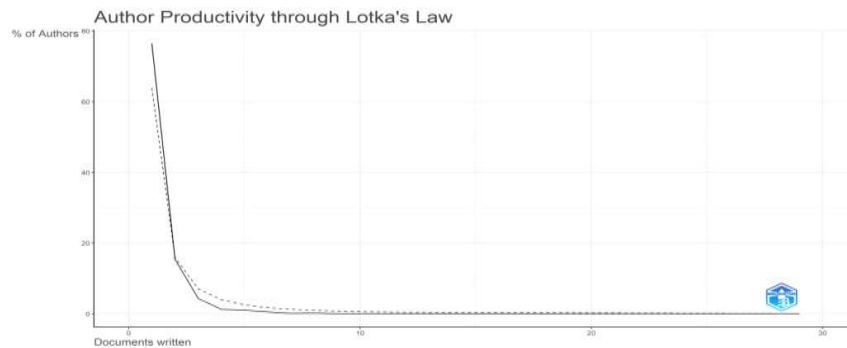


Fig.12. Lotka's law for authors' productivity, performed with Biblioshiny.

In particular, only seven authors have written four or more articles in the analyzed area. Lotka's law of scientific productivity shown in Fig. it indicates that a total of 1919 authors published articles during the period 2007 to 2024. Here, Lotka's law reveals that about 16.84% of the authors 8 have one publication, and approximately 60.14% of the authors 11 have two publications.

G. Most Productive Authors

Table 3 lists the most productive authors in the field of Droop inverter control techniques in AC Microgrid research. The author, Rocabert J.; Luna A.; Blaabjerg F.; Rodrguez P. affiliated with the University of Department of Electrical Engineering, Technical University of Catalonia, 08222 Barcelona, Spain; 2012 had publications 3324, and was cited 3710 times with a citation impact of 89.59%. The authors Guerrero J.M.; Vásquez J.C.; Matas J.; Castilla M.; Garca de Vicuna L. affiliated with the University of 2009 had publications 1166, and was cited 665 times with a citation impact of 57 USA produced 294 publications and 201 citations respectively is at the bottom of the lists and a citation impact of 68.36%. The overall results of the productive authors indicate that this is an emerging area and has scope for significant researchers in the future.

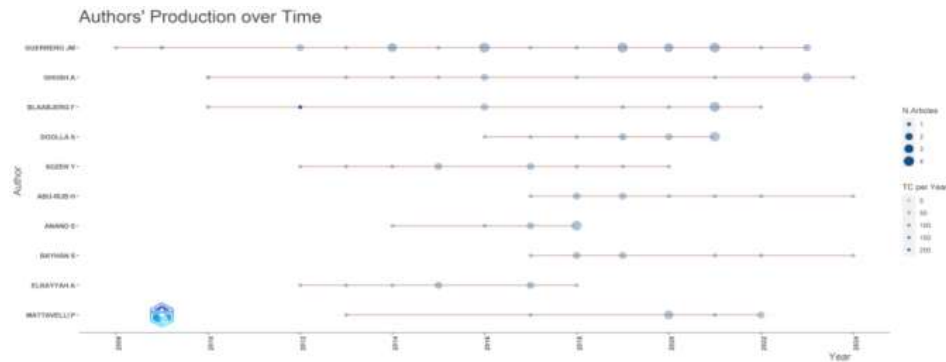


Fig. 13. author production over time with Biblioshiny version 4.3

TABLE I: THE TOP 5 MOST INFLUENTIAL AUTHORS IN THE FIELD OF DROOP INVERTER CONTROL TECHNIQUE IN AC MICRO GRID H-INDEX DURING THE PERIOD 2000 AND 2024.

Authors	Affiliations	Year	TC	TP	C/P	H-index
Rocabert J.; Luna A.; Blaabjerg F.; Rodríguez P.	Department of Electrical Engineering, Technical University of Catalonia, 08222 Barcelona, Spain; Green Power Laboratory, Institute of Energy Technology, Aalborg University, 9220 Aalborg, Denmark; Abengoa Research, 41014 Seville, Spain	2012	2868	3394	0.84	17
Guerrero J.M.; Vásquez J.C.; Matas J.; Castilla M.; García de Vicuna L.	Department of Automatic Control Systems and Computer Engineering, Technical University of Catalonia, 08036 Barcelona, Spain; Department of Electronic Engineering, Technical University of Catalonia, 08800 Vilanova i la Geltrú, Spain	2009	732	665	1.1	15
Barklund E.; Pogaku N.; Prodanovic M.; Hernandez-Aramburo C.; Green T.C.	Department of Electrical and Electronic Engineering, Imperial College London, London SW7 2AZ, United Kingdom	2008	678	608	1.11	13
Majumder R.; Chaudhuri B.; Ghosh A.; Majumder R.; Ledwich G.; Zare F.	School of Engineering Systems, Queensland University of Technology, Brisbane, Australia; Department of Electrical and Electronic Engineering, Imperial College London, London, United Kingdom; Power Technologies, ABB Corporate Research, Västerås, Sweden	2010	639	212	3.01	11
Augustine S.; Mishra M.K.; Lakshminarasamma N.	Department of Electrical Engineering, Indian Institute of Technology Madras, Chennai, India	2015	411	218	1.88	11

This table lists the top 05 authors on the Droop inverter control technique in AC micro grid with at least 223 publications and 201 citations between 2000 and 2024. It also shows the institution and country affiliated with the author, total number of publications by each author 223, total citations associated with these publications 201, citations per publication 1.1, and 7 h-index (h).

H. Analysis of Author Collaboration Networks

Collaboration between authors was also analyzed. In particular, the collaboration network shows research groups that are working on specific topics and how they are related in addition to the individualization of the largest research group in the analyzed area. Fig.14 shows a total of 12 research groups for the analyzed topic. The biggest group is composed of 12 authors out of 12 groups, which are composed of only two members.

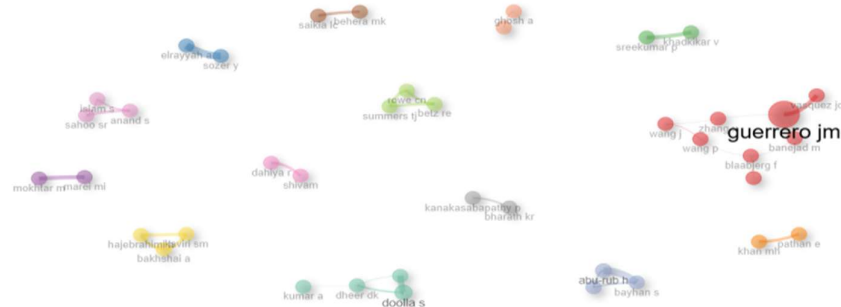


Fig. 14. Collaboration network analysis, performed with Biblioshiny version 4.3

I. Authors' Impact

Based on the determination of the H index, the G index, the M index, and the total citations, a study of the authors' influence was also conducted. According to gurrero.jm, "the H-index has rapidly become one of the most favoured measures of scientific output" and is used to compare academics' scientific achievements objectively. The number of publications that have received at least one citation is counted to calculate the index (29).

"The highest number G of papers that together received 2 or more citations" is how the G-index is defined; it is higher than the H-index.

The M index is the H index divided by "the number of years since the first publication of an author" Rocabert J.; Luna A.; Blaabjerg F.; Rodrguez P. with the ten most important authors. The author with the highest impact is gurrero.jm., who is a Professor of the Electrical

Engineering Department, Technical University of Catalonia, 08222 Barcelona, Spain; Green Power Laboratory, Institute of Energy Technology, Aalborg University, 9220 Aalborg, Denmark; Abengoa Research, 41014 Seville, Spain.

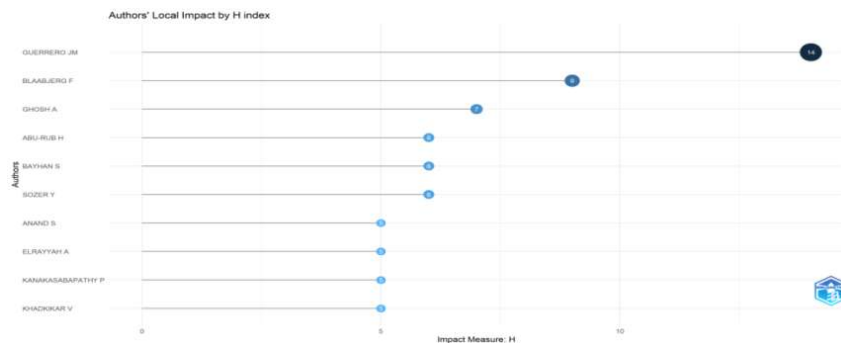


Fig. 15. Impact analysis of the authors performed with Biblioshiny version.

J. Sources Analysis

Source analysis is useful for identifying the most relevant journals in a specific subject area. This type of analysis was conducted using the Biblioshiny software.

K. Bradford Law

Bradford's law allows 'identifying the core journal in a given field Energies; in particular, it 'reveals a pattern of how the literature on a subject is distributed in journals' Energies. Therefore, this law is useful for the individuation of journals that are more committed to a specific field drop control inverter technique in the ac Microgrid. Furthermore, it makes possible the division of journals into three zones, where 'Bradford called the first zone the nucleus of periodicals particularly devoted to the given subject' Microgrid. The other two zones are the middle third, which includes a journal with an average citation amount, and the bottom third, with journals of marginal importance in the related field IEEE journal of emerging. The law "predicts that the number of journals in the second and third zones will be n and n^2 times larger than the first zone, respectively" Energies. This type of analysis was performed by Biblioshiny and the output is as shown in Fig.20. The first zone in which the core sources are included is composed of four journals, i.e. Energies, IEEE transactions on SG, IEEE transactions on power electronics and lecture notes in electrical engineering. The four journals belonging to the central zone have produced a total number of articles equal to 30. In the second zone, 20 journals are present, whose production is equal to 20 articles, and finally, in the third zone, 10 journals are present, with a production 30 articles.

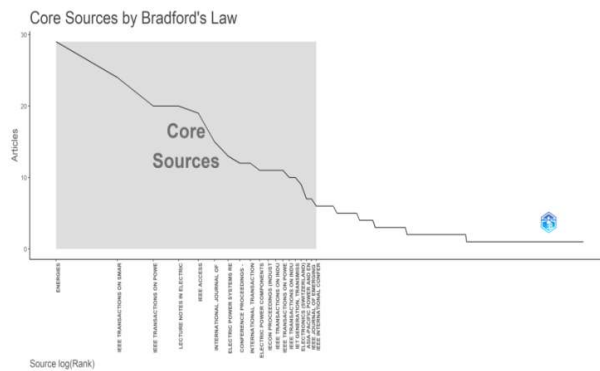


Fig. 16. Source clustering according to Bradford's law, performed with Biblioshiny version 4.3

L. Sources' Dynamics

The dynamics of the core sources was analyzed over time. In Fig.21, the temporal trend is shown for the number of articles published by journals on the analyzed topics. Fig.22 shows a general increasing trend for the number of articles on Energies, IEEE Access, and IEEE transactions in power electronics. In particular, the journal Energies has the highest number of occurrences in the year 2013, followed by the journal IEEE Access, with 20 occurrences in 2021. Two journals IEEE transaction in power electronics. and IEEE transaction in power electronics.

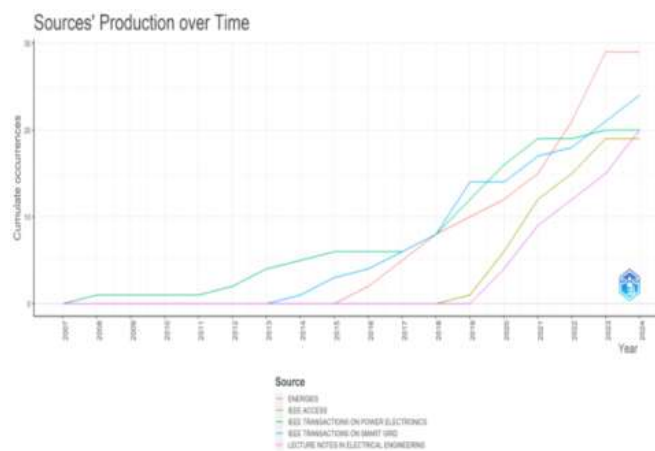


Fig.17. Sources' article publication by year analysis, performed with Biblioshiny version 4.3

M. Impact of Sources

In Table 2, the ten sources with the highest impact in the studied topics are listed. Regarding Bradford's law and the analysis of the most relevant sources, the source with the greatest impact is automation in construction, followed by sustainability and applied sciences.

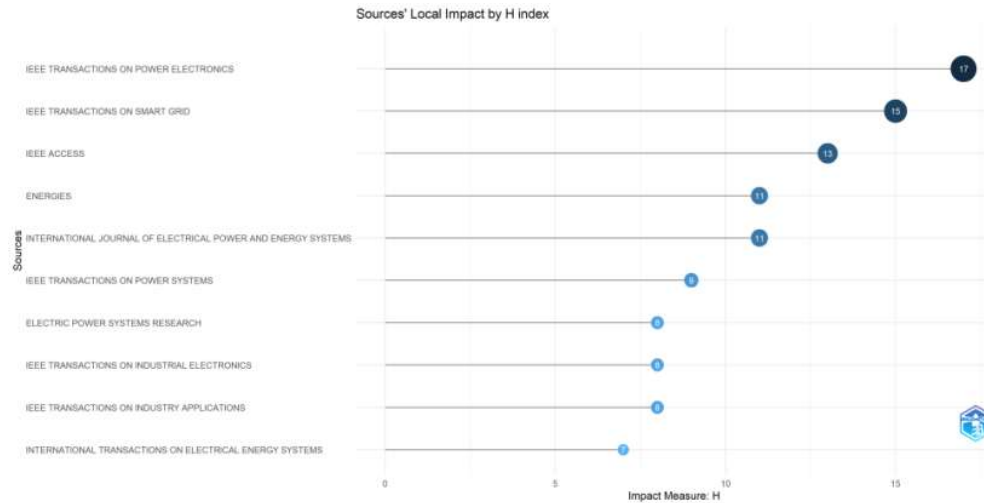


Fig. 18. Impact analysis of sources, performed with Biblioshiny version 4.3

N. Three-Field Plots:

Three fields were connected to each other proportionate to the node's value using Sankey plots (Fig. 20). The lists in the left, centre, and right rows, respectively, contain the authors, keywords, and sources that were selected for examination.

O. Three-Factor Analysis: Keywords, Authors and Sources

The published literature on Droop inverter control technique in AC microgrid is shown in Fig.20, with an emphasis on the relationships between the main keywords, authors and sources. The study's findings revealed the leading authors of the Droop inverter control technique in AC microgrid, as well as the sub-areas and recommended source for publications. Fig.19 illustrates the strong correlation between the top three authors, Kundur, P., Chandorkar, M. C. Dwarkan and Pogaku, P., and five subareas, Droop control, Micro grid(MG), Smart Grid(SG), Distributed Generation(DG), and Centralized Mode, with the Droop inverter control technique in the AC Micro grid. Moreover, these writers favoured publishing in three different venues: smart grid, micro grid, and Droop Control Technique.

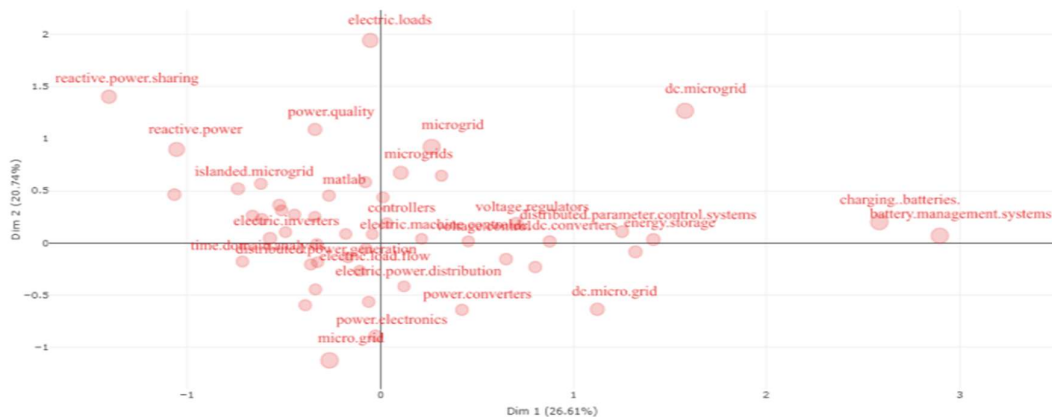


Fig.19. Three-factor analysis of the relationship among keywords (left) sources (middle) and countries (right).

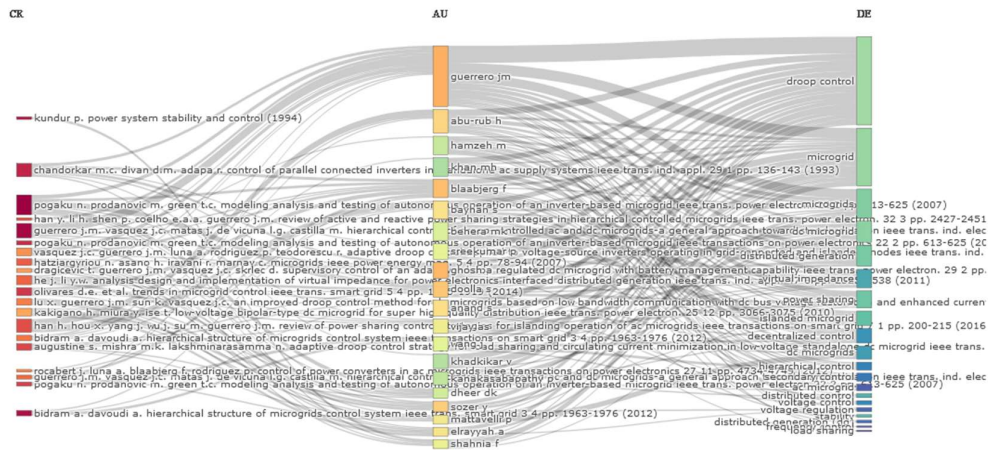


Fig.20. Three-Factor Analysis, performed with Biblioshiny version 4.3

P. Three-Factor Analysis: Keywords, Sources and Countries

Fig.20. illustrates the correlation between study topics (keywords), sources, and nations regarding the Droop inverter control technique in AC microgrid studies. Droop control, distributed generation, microgrid, controller, and electric inverters were the five main subject areas. These five subject areas were related to the other five sources described above. Furthermore, these subject areas had a strong relationship with the two top most productive countries, i.e., SPIAN and CHINA.

Q. Thematic Focus of The Field of Droop Inverter Control Technique In AC Micro Grid

The following section analyses the most common topics and areas of interest for Droop inverter control technique research in AC micro grids across scholars over time. Additionally, the study seeks evidence of a change in the subjects that academics in the field are discussing. The keywords used by the authors are examined in this paper along with how often they appear. Additionally, it provides a study of the field's thematic areas, co-occurrence network, trending topics, and keyword dynamics.

R. Keyword Analysis, Cooccurrence Network and Trend Topics

Analysis of Keywords

An important method for examining current topics and scholars' areas of interest is keyword analysis employed by writers in their writings. The reason for this study is that publication keywords make it easier to quickly determine the subject and purpose of that article. The Droop inverter control technique in AC Micro grid's word cloud, depicted in

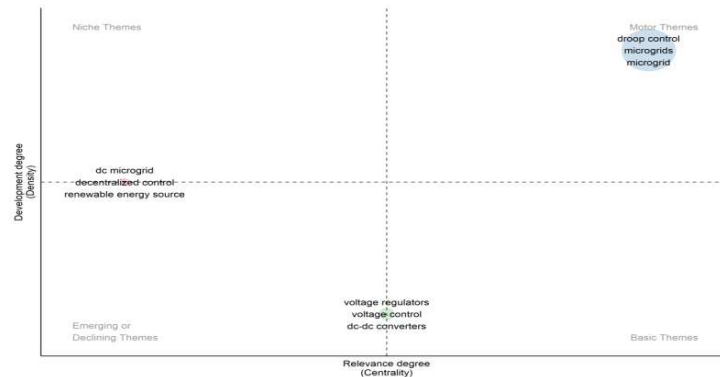


Fig. 21. Thematic focus of the field of Droop inverter control technique produced from bibliometric.

Fig.22, displays often used keywords

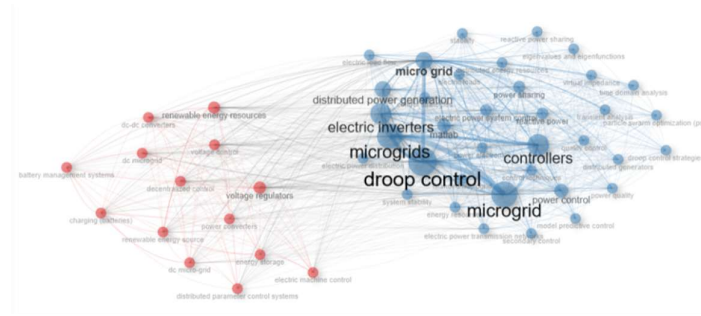


Fig.24. Co-occurrence keyword network map analysis performed with VOS viewer

U. Trending Topics

Fig.25 shows 20 topics summarized in the past 24 years, by looking at the term frequency which is classified into four frequencies (100, 200, 300, 400), one can understand the focus of Droop inverter control technique in AC Microgrid every year. Research on the topic of microgrid began around 2007 and began to experience exponential growth around 2007 to 2024; this is estimated to be due to the impact of power quality and other factors that cause voltage regulation to increase in distributed generation.

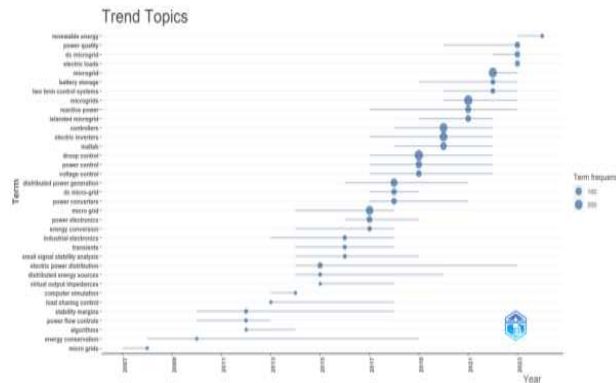


Fig.25. Trend Topics in the field of Droop inverter control technique in AC Microgrid

V. Thematic Map of Keywords

Thematic mapping allows four different topic typologies to be shown, as Fig.26 illustrates. The theme map makes use of the keyword field. In this two-dimensional graph, themes are arranged in groups based on centrality and density. The X-axis represents the centrality, which is a measure of a theme's significance or relevance. The density that represents the development stage of a theme is displayed on the Y-axis. The themes are categorized and arranged into four quadrants (Fig.26), which are explained in the sections that follow. The upper right quadrant (Q1) has motor themes. These topics have a high centrality and density, indicating their significance and level of development. The primary themes in this analysis include controllers, microgrids, and droop control. The themes in this quadrant are well developed and well researched, which makes them perfect for in-depth literature reviews and scientometric analyses.

- The lower right quadrant contains the fundamental themes (Q2). This quadrant's high centrality and low density indicate that it contains significant but underdeveloped themes. The themes of this quadrant are DC-DC converter, voltage control, and voltage regulation.
- The primary themes are located in the lower right quadrant (Q3). The low density and high centrality of this quadrant suggest that its themes are substantial but not well explored. Voltage control, voltage regulation, and DC-DC converter are the themes in this quadrant.
- The upper left quadrant (Q4) contains extremely specialized/niche themes. There is little centrality and high density in this area. Even though topics like DC microgrids are quite advanced, there is not as much centrality in AC microgrids; therefore there is still isolation when it comes to Droop inverter control technique.

The study has used the authors' keywords and criteria, which are Minimum Cluster Frequency (per thousand documents)-5 and Number of Words (250).

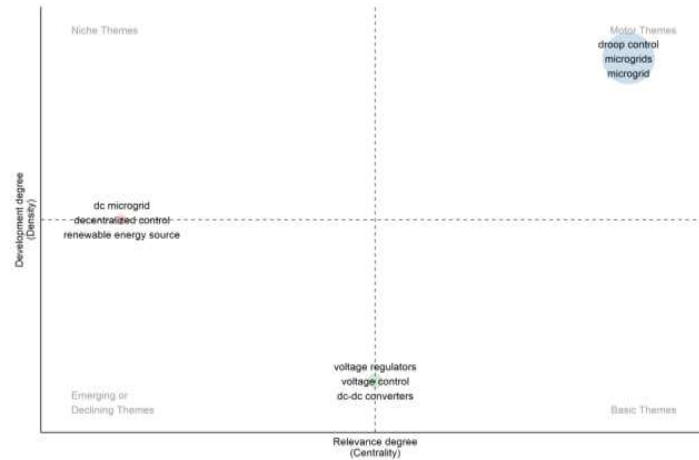


Fig. 26. Thematic mapping of keywords

X. CONCLUSION

The operating modes and techniques for control for distributed generation (DG) units in Micro Grid have been outlined in this paper using a Scientometrics framework, with a focus on grid-connected and island modes. Through our review, we have investigated a variety of control techniques at various levels, emphasizing their usefulness in diverse contexts. The regulation of voltage and frequency, efficient power management among DG units, integration of RESs, and seamless changeover between the modes of functioning are only a few of the major issues that micro-grids must deal with, as we have identified and explored. The evolution of micro-grid technologies depends on addressing these issues, which are crucial to the creation of a flexible and intelligent distributed power system. The research presents a Bibliometrics study from 2000 to 2024 in response to these problems. Droop control has been emphasized as a critical tactic for handling the dynamic and decentralized structure of the micro grid, particularly in island operations where the stability and dependability of the power supply are critical. We have also emphasized the usefulness of applying these control mechanisms in actual situations. The Scientometrics study offers important insights into the gap between theoretical research and practical application and aids in understanding the practical issues and concerns of adopting droop control in micro-grid. This gap offers a chance for more in-depth study and advancement in the area. Research on the integration of renewable energy sources (RES) and production of reliable and efficient control mechanisms will continue to be crucial as microgrid technologies advance. With improvements in control techniques and technology opening the door to more sustainable, reliable, and efficient power systems, microgrids have a bright future. As a result, this work adds to the body of knowledge by outlining problems and future possibilities for micro grid control systems in addition to assessing the state of the art. It provides a basis for additional research and innovation in micro-grid technologies, making it a useful tool for practitioners and researchers in the sector.

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