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Analysis of System Reporting and Validation in DC Microgrid DSC Research: An Ex Post Facto Reproducibility Study

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Abstract

Distributed secondary control (DSC) is essential for voltage regulation and current sharing in DC microgrids with high renewable penetration. However, the diversity of system configurations, control strategies, and validation approaches challenges the reproducibility of published results. This study evaluates reporting and validation practices in 74 DSC-related articles from a reproducibility and research ethics perspective. Using a document-based ex post facto design, we construct a Reproducibility Readiness Index (RRI) based on system configuration reporting, validation completeness, and performance metric clarity. Results show that most studies exhibit low to medium reproducibility readiness, with only about one third achieving high levels. While system descriptions are generally adequate, validation setups and performance metrics are often incomplete or qualitative. Studies including hardware-in-the-loop or prototype experiments tend to score higher, though weak documentation remains a major limitation. These findings emphasize reproducibility as both a technical and ethical concern and support the need for stronger transparency and open science practices in DSC research on DC microgrids.

Keywords: DC Microgrid; Distributed Secondary Control; Reproducibility; Ex Post Facto; Open Science

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1. Introduction

The transformation of power systems toward cleaner, more decentralized, and more flexible energy mixes has driven the development of microgrid architectures, particularly DC microgrids. Various studies show that DC microgrids offer simpler energy conversion paths, high efficiency for integrating renewable energy and energy storage, and convenient interfacing with modern electronic loads across market segments such as commercial buildings, industry, transportation, and remote communities [1].

To ensure power quality and operational reliability, DC microgrids are generally controlled using a hierarchical control scheme consisting of primary, secondary, and tertiary levels. Several comprehensive reviews have discussed the role of primary control (e.g., droop control) in local current/power sharing, as well as secondary control for correcting voltage deviations and improving current/power sharing performance [2], [3]. In this architecture, secondary control restores the DC bus voltage to its nominal value while improving the accuracy of current sharing on top of the droop layer.

In recent years, research focus has shifted from centralized secondary control approaches to distributed secondary control (DSC), which exploits communication networks among converters and consensus algorithms to achieve coordinated current sharing and voltage restoration without a single point of failure [3]–[5]. Recent works have proposed various DSC schemes to address practical issues such as communication delays, packet loss, false data injection attacks, nonlinear/ZIP loads, and constant power loads [6]–[14]. The proposed approaches include consensus-based control, event-triggered control, passivity-based design, and multi-agent reinforcement learning and optimization strategies [7], [10], [12], [15]–[18].

This diversity of control approaches, system configurations, and validation methods makes the DSC in DC microgrids a scientifically rich field, but it also creates challenges in terms of comparability and reproducibility across studies—especially when system configuration documentation and experimental setups are not reported consistently and in sufficient detail [6]–[14], [19]–[25]. In practice, DSC designs are usually tested through detailed simulations (e.g., in MATLAB/Simulink) and, in some studies, complemented with hardware-in-the-loop (HIL) validation or laboratory prototypes [1]–[5], [6]–[14].

In contemporary scientific discourse, reproducibility and replicability are regarded as essential prerequisites for maintaining the credibility of science. A National Academies report emphasizes that non-reproducible research results (due to weak experimental design, poor documentation, and the absence of data/code) can erode public trust in science and hinder the advancement of knowledge [26]. Debates about the replication crisis across disciplines likewise show that inadequate reporting practices and poor data governance significantly contribute to the difficulty of repeating and verifying scientific findings [27].

In response, the open science movement promotes a set of practices such as openness of data, code, and protocols, preregistration of studies, and more transparent methodological reporting as ways to improve reproducibility [27], [28]. This approach is not merely technical, but also strongly normative: openness is seen as a way to strengthen the relationship between the research system and society, and to operationalize the principle "as open as possible, as closed as necessary" in a contextual and responsible manner [28].

At the same time, the engineering and applied science communities have increasingly stressed that responsible and ethical conduct of research includes the obligation to produce and disseminate knowledge with rigor and integrity, including maintaining data traceability, methodological transparency, and ease of verification by other researchers [26], [29], [30]. Policies and training programs on Responsible and Ethical Conduct of Research (RECR) position reproducibility as a component of good scientific practice, alongside other aspects such as honesty in reporting, conflict-of-interest management, and the protection of research subjects.

In the context of DSC on DC microgrids, the issue of reproducibility becomes highly relevant because: (1) most studies rely on numerical simulations and complex system modeling; (2) control performance is evaluated under specific disturbance scenarios and system configurations; and (3) the results are potentially adopted in the design of power systems that are critical for supply reliability [1]– [5], [6]– [14]. When system configuration details, converter parameters, load characteristics, communication networks, and validation procedures are not reported adequately, other researchers will find it difficult to repeat experiments, verify performance claims, or fairly compare different DSC approaches. This is not merely a technical problem, but also relates to the ethical responsibility of researchers to provide a robust foundation for real-world technology deployment [26]–[30].

Although numerous studies have proposed diverse distributed secondary control (DSC) schemes for DC microgrids—ranging from classical consensus-based methods to event-triggered, game-theoretic, and reinforcement learning-based approaches—most of these works primarily emphasize algorithmic novelty and performance enhancement. While such contributions have significantly advanced the development of DSC, they also introduce reproducibility challenges arising from heterogeneous experimental setups, validation strategies, and performance evaluation metrics across studies. Consequently, limited attention is given to critical reflection on the completeness and consistency of system reporting and validation practices, which are key determinants of reproducibility readiness [3]–[5], [6]–[14], [19]–[25]. To date, only a very limited number of studies have systematically addressed these issues, including assessing the completeness of system configuration reporting (DC microgrid topology, source and load parameters, converter and network characteristics) in DSC articles, evaluating the clarity of validation methods (types of simulations, HIL, prototypes) along with the test scenarios and performance metrics used, and quantifying the extent to which the information provided in publications is sufficient to enable reproduction of the results by other researchers.

Based on this background, the present article is designed as a document-based ex post facto study of 74 articles discussing DSC on DC microgrids [6]–[25]. The extracted article data are used to describe system configuration and validation method reporting practices in DSC DC microgrid publications, focusing on the completeness of technical information and performance metrics; construct and apply a reproducibility readiness index that combines indicators of system reporting, validation methods, and performance metrics; analyze factors associated with the level of reproducibility readiness, such as type of validation method, system configuration complexity, and publication characteristics (e.g., year, type of venue); and interpret the findings from the perspective of research ethics and open science, formulating practical recommendations for researchers, journals, and institutions to improve the reproducibility of DSC research on DC microgrids. Thus, this article is expected to make a dual contribution: (i) providing an empirical picture of the current state of reproducible research practices in the DSC DC microgrid domain, and (ii) strengthening the application of research ethics and open science principles in the power systems research community.

2. Methods

2.1 Research Design

This study employs a document-based ex post facto design, in which the researcher does not intervene in or manipulate variables, but instead analyzes characteristics that are already embedded in published scientific articles. This approach is aligned with the aim of the study, namely to evaluate system reporting practices and validation methods in DSC research on DC microgrids and to assess reproducibility readiness based on the information available in the publications.

From the perspective of research ethics and responsible conduct of research, this literature-based ex post facto design is relatively low risk because it does not involve human subjects directly. However, it still requires careful interpretation and reporting to avoid misrepresenting the scientific work of others [26], [29].

2.2 Data Sources and Article Selection

The research data are drawn from 74 scientific articles that discuss DSC in DC microgrids. These articles are the result of an earlier search and screening process and were compiled into an extraction sheet (spreadsheet) containing summaries of key information for each article. Examples of articles analyzed include the work of

Silva et al. on a voltage-shifting strategy for power sharing and voltage restoration [6], studies by Peng et al. on self-triggered and event-triggered control with communication delays [7], [12], the work by Bai et al. on voltage regulation and current sharing in multi-bus DC microgrids [8], as well as other approaches based on robust/adaptive control, passivity-based control, and multi-agent reinforcement learning [9]–[18], [21]–[25].

In general, the inclusion criteria for the articles are as follows:

1. The article addresses DC microgrids as the main system (not AC microgrids or general power systems).
2. The article proposes or analyzes distributed secondary control (e.g., consensus-based, event-triggered, droop with distributed secondary, robust/adaptive, or learning-based approaches) [2]– [5], [6]–[18].
3. The article presents results of simulations, HIL, or prototype experiments used as validation methods [1], [6]–[14], [19]–[25].
4. The article is published in a reputable journal or conference proceedings (indexed and/or from major publishers in electrical engineering and energy).

The publication years follow those recorded in the extraction sheet (in general reflecting the development of DSC DC microgrid literature in recent years). Focusing on a single specific domain (DSC in DC microgrids) allows for sharper analysis of reporting practices within a research community that is relatively homogeneous in technical terms.

2.3 Data Extraction Process

The extraction sheet used in this study contains the following columns (summary): 1) Bibliographic information: Title, Authors, Year, Venue, Citation count; 2) Technical control characteristics: Control Strategy Type, Technical Mechanism, Communication Characteristics, Current Sharing Method, Voltage Restoration Method, Key Performance Features; 3) System and validation characteristics: System Configuration, Validation Method; and 4) Additional notes: for example, supporting notes/quotes explaining the summaries above.

These columns were originally designed for a technical review of DSC in DC microgrids, but in this study they are repurposed as an ex post facto dataset to evaluate reproducibility.

The analysis steps began with:

1. Checking the consistency of extraction data, i.e., ensuring that each article has information filled in the key columns (System Configuration, Validation Method, Key Performance Features), or explicitly marking “not mentioned” if certain information is indeed absent.

2. Re-reading the summaries in those columns and, where necessary, referring back to the original articles to clarify interpretation, especially when assigning scores (coding) for ordinal variables [6]–[14].
3. Developing a coding scheme to convert qualitative information in the extraction sheet into quantitative/ordinal variables that can be analyzed. This scheme was constructed with reference to openness and transparency principles in reporting as emphasized in the reproducibility and open science literature [27], [28].

2.4 Variables and Operational Definitions

Dependent Variable: Reproducibility Readiness Index (RRI)

The main dependent variable in this study is the RRI of each article. RRI is built from three indicators, all derived from the extraction data; the indicators and their ordinal scales are summarized in **Tabel 1**.

Tabel 1. Dependent variable and ordinal-scale assessment indicators

No.	Dependent Variable	Ordinal Indicator
Y1	Completeness of System Configuration Reporting	0 (low): only mentions "DC microgrid"/"multi-bus" in general, without information on the number/type of DER, loads, or important parameters. 1 (medium): mentions the topology (e.g., single-bus, multi-bus radial) and some system elements, but key parameters or component details are still missing. 2 (high): explains the topology, number and types of DER/loads, main voltage/power ratings, as well as line/converter parameters in sufficient detail to reconstruct the model.
Y2	Completeness of Validation Method Reporting	0 (low): only states that "simulation results are presented" without explaining the platform, test scenarios, or experimental setup. 1 (medium): mentions the simulation platform (e.g., MATLAB/Simulink, PSCAD) and/or types of tests (step load, plug-and-play, voltage disturbances), but setup details (key parameters, simulation duration, HIL/prototype configuration) are still minimal. 2 (high): explains the platform, test scenarios, main parameters, and HIL or hardware prototype setup (equipment used, configuration, system scale) in sufficient detail.
Y3	Clarity and Richness of Performance Metrics	0 (low): only provides qualitative claims (e.g., "faster response," "better performance") without numerical values or explicit metrics. 1 (medium): presents 1–2 numerical metrics (e.g., overshoot, steady-state error) but without consistency or clear evaluation context (e.g., unclear test scenarios). 2 (high): presents several quantitative metrics (e.g., settling time, overshoot, current sharing error, voltage deviation) systematically and, ideally, with comparisons to other methods.

The RRI value for each article is calculated as RRI = Y1 + Y2 + Y3, Thus, RRI ranges from 0 to 6, and is then categorized as: 0–1 (very low), 2–3 (low), 4–5 (medium), and 6 (high). This RRI construction is consistent with the principle that reproducibility in engineering research strongly depends on the transparency of the system, validation methods, and evaluation metrics used [27], [28].

Independent Variables: Presumed Influencing Factors

Several independent variables (X) are derived from other columns in the extraction sheet, as summarized in **Tabel 2**.

Tabel 2. Independent variables

No.	Independent Variable	Description
X1	Year of Publication	Used to observe whether there is a trend of increasing RRI over time (e.g., due to the influence of the open science movement).
X2	Type of Control Strategy	Nominal categories: 1 = consensus-based DSC; 2 = event-triggered/self-triggered; 3 = others (robust/sliding/finite-time/adaptive/learning-based).
X3	Complexity of Technical Mechanism	Ordinal scale (0–2) based on qualitative assessment: 0 = simple (e.g., droop + PI); 1 = medium (e.g., consensus with simple observer); 2 = high (e.g., high-order observer, complex robust/sliding mode).
X4	Communication Characteristics	Ordinal scale (0–2): 0 = not modeled/not explained; 1 = modeled in a simple way (graph topology without delay/loss details); 2 = modeled relatively in detail (delay, packet loss, explicit graph aspects).
X5	System Topology Complexity	In addition to being used in Y1, topology is coded as: 0 = simple single-bus; 1 = multi-bus radial; 2 = multi-bus/meshed or multi-area complex.
X6	Validation Method Category	Nominal categories: 1 = simulation only; 2 = simulation + HIL; 3 = simulation + hardware prototype.

These variables were selected to represent both the technical dimension (e.g., control and system complexity) and the publication ecosystem dimension (year, venue, citations), which theoretically may influence the quality of reporting practices and reproducibility [2]–[5], [27], [28].

2.5 Data Analysis Procedure

Data analysis was conducted in several steps:

1. Descriptive Analysis:
    - Calculating descriptive statistics (mean, median, distribution) for RRI and each indicator Y1–Y3.
    - Presenting frequency distributions for the categories of X variables (e.g., validation method type, venue type, control strategy type).
2. Simple Relationship Analysis:
    - Constructing cross-tabulations between RRI categories and key variables, namely the validation method category (X6).

- Using simple association tests (e.g., chi-square test) or non-parametric correlations (e.g., Spearman) to examine trends in relationships between ordinal/numeric variables (e.g., X1 and RRI).

3. Qualitative Interpretation:
   - For selected interesting cases (e.g., articles with very high or very low RRI), performing more in-depth reading of the original texts to provide concrete illustrations of good and problematic reporting practices [6]–[14], [19]–[25].
   - Interpreting the quantitative findings and qualitative examples in the framework of research ethics and open science as discussed in Chapter 1 [26]– [28].

2.6 Considerations and Limitations

Although this study does not involve human subjects, it still touches on ethical aspects because it evaluates the quality of reporting of other researchers' scientific work. In line with responsible conduct of research guidelines, this study: (1) does not explicitly mention authors' names or article titles when presenting negative examples (low RRI), unless necessary as illustrations and then still presented fairly and proportionally; and (2) strives to maintain objectivity in assessment through explicit and consistent coding criteria, even though ordinal ratings inevitably contain elements of subjectivity [26], [29], [30].

The main limitations of this study are: (1) RRI is constructed based solely on information available in the published text; the study does not reimplement models or experiments, so the reproducibility assessed is reporting-based reproducibility, not empirical replication; (2) ordinal variables are coded by a single researcher (single coder), so inter-rater reliability cannot be formally evaluated; and (3) the narrow domain focus (DSC in DC microgrids) limits direct generalization to other fields, but at the same time becomes a strength for in-depth analysis of one specific research community [2]–[5], [6]–[25].

3.Results and Discussion

3.1 General Profile of the Articles Analyzed

This section presents an overview of the 74 articles analyzed, including the distribution of publication years and the characteristics of the control approaches and validation methods used. This information is important for understanding the development context of DSC research on DC microgrids before discussing reproducibility in more detail [2]–[5].

Out of the 74 articles, approximately 56.8% employ a pure consensus-based approach, 9.5% combine event/self-triggered mechanisms with distributed secondary control, and 33.8% adopt other approaches such as sliding-mode, robust, or adaptive control [3]–[5]. In terms of validation methods, about 21.6% of the articles rely solely on simulations, while the remaining 78.4% already involve HIL and/or hardware prototypes, which potentially provide a stronger empirical basis for evaluating control performance, as shown in **Tabel 3**.

Tabel 3. General profile of DSC articles on DC microgrids analyzed in this study

Group	Category	Number of Articles (N)	Percentage (%)
Publication period (X1)	2020–2021	21	28.4
	2022–2023	24	32.4
	2024–2025	29	39.2
Control strategy type (X2)	Consensus-based DSC (1)	42	56.8
	Event/self-triggered DSC (2)	7	9.5
	Others (3)	25	33.8
Validation method (X6)	Simulation only (1)	16	21.6
	Simulation + HIL (2)	27	36.5
	Simulation + hardware prototype (3)	31	41.9

3.2 Distribution of the Reproducibility Readiness Index (RRI)

RRI is calculated for each article based on three indicators: completeness of system configuration reporting (Y1), completeness of validation method reporting (Y2), and clarity of performance metrics (Y3). The RRI value ranges from 0 to 6. For descriptive analysis, RRI is grouped into five categories: very low (≤2), low (3), medium (4), high (5), and very high (6).

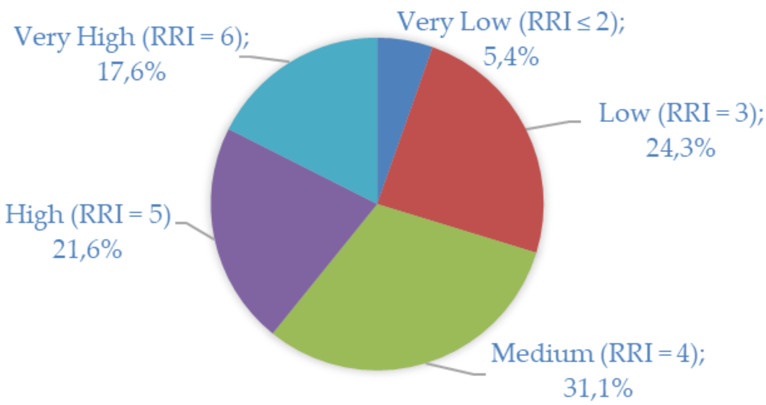

Figure 1. Distribution of the RRI

The results show that articles achieving a very high RRI (RRI = 6) account for around 17.6%, and about 21.6% fall into the high category (RRI = 5), as shown in Figure 1. Most articles (31.1%) are in the medium category (RRI = 4), while 24.3% are in the low category (RRI = 3), and the remaining 5.4% are classified as very low (RRI ≤ 2). These findings indicate that, in general, reporting practices in DSC research on DC microgrids tend to be at a medium to low level of reproducibility readiness, although some articles already show relatively good documentation efforts.

3.3 Configuration Reporting Practices (Y1)

The first aspect evaluated is the completeness of DC microgrid system configuration reporting, which includes information on topology, types and numbers of DERs, load characteristics, and key converter and line parameters. Good system configuration reporting is crucial because the system model is the basis for all simulation results and control performance analyses [2]–[4].

Of the 74 articles, about 95.9% provide detailed descriptions of the system configuration (Y1 = 2), for example by presenting one-line diagrams, tables of converter and line parameters, voltage and power ratings, and load characteristics. The remaining 4.1% of articles only provide partial information (Y1 = 1), such as merely mentioning a single-bus or multi-bus topology and some component ratings, while omitting several important parameters.

Descriptively, these figures show that most DSC studies on DC microgrids have relatively good practices in reporting system configurations. However, when considered in relation to the other indicators (Y2 and Y3), high Y1 scores do not automatically guarantee high reproducibility readiness, because there are still significant weaknesses in validation methods and performance metrics. In other words, the system model is generally quite transparent, but the validation flow and how control success is measured are not always documented to the same extent.

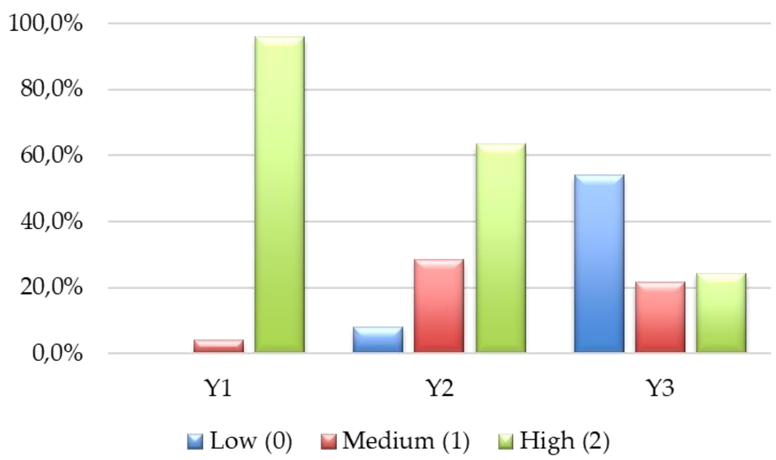

Figure 2. Percentage values for Y1–Y3 indicators

3.4 Validation Method Reporting Practices (Y2)

The second aspect concerns the completeness of validation method reporting, which includes the simulation platform, types of test scenarios, and details of hardware-in-the-loop (HIL) or prototype experiments. In microgrid control research, differences in validation methods (pure simulation, HIL, or prototype) have a major impact on the strength of performance claims [1], [2], [4].

Based on the coding results, around 21.6% of the articles use pure simulation as the main validation method, 31.1% combine simulation with HIL, and 47.3% include laboratory-scale prototype experiments (Table 1). However, in terms of Y2 scores, only about 63.5% of the articles provide highly detailed validation method descriptions (Y2 = 2), including the simulation platform, HIL or prototype configuration, and key test scenario parameters. A considerable proportion, 28.4%, fall into the medium category (Y2 = 1), where explanations are limited to brief statements such as "simulations are carried out in MATLAB/Simulink", without further details. The rest are in the lowest category (Y2 = 0).

This indicates that the presence of HIL or prototype experiments does not automatically guarantee high reproducibility readiness; the determining factor is how thoroughly the setup is documented. These findings are consistent with the reproducibility literature, which emphasizes that weak methodological documentation is one of the root causes of difficulty in replicating research results [26]–[28].

3.5 Performance Metrics and Result Reporting (Y3)

The third indicator, Y3, concerns the clarity and richness of performance metrics used to evaluate DSC, such as settling time, voltage overshoot, current sharing error, and steady-state voltage deviation. Clear and measurable metrics are essential for enabling fair comparisons among proposed control schemes [2]– [4].

The analysis shows that about 24.3% of the articles present performance metrics systematically (Y3 = 2), for instance by showing dynamic response curves along with settling time, overshoot, and steady-state error values for several disturbance scenarios. Around 21.6% of the articles belong to the medium category (Y3 = 1), because they report only one or two numerical metrics without clear consistency. Meanwhile, 54.1% of the articles remain in the low category (Y3 = 0), as most performance claims are qualitative, such as "the proposed method shows better performance", without sufficient numerical support.

Such limited quantitative reporting practices hinder efforts to benchmark DSC approaches and ultimately reduce the scientific value of performance improvement claims. From a reproducibility perspective, the lack of clear metrics makes it difficult for other researchers to determine whether a re-implementation of a method has achieved performance that is "equivalent" to that in the original publication. The percentages of all dependent variable indicators are shown in **Figure 2**.

3.6 Relationships Between Factors and Reproducibility Readiness

After obtaining RRI values for each article, the analysis proceeds to explore the relationships between RRI and several independent variables (X), one of which is the validation method category (X6). This analysis aims to identify factors that appear to contribute to high or low reproducibility readiness in DSC research on DC microgrids

Tabel 4. Cross-tabulation of the RRI and validation methods (X6)

RRI Category	Simulation only (X6 = 1)	Simulation + HIL (X6 = 2)	Simulation + prototype (X6 = 3)	Total
Very low	0	0	4	4
Low	8	7	3	18
Medium	6	8	9	23
High	2	7	7	16
Very high	0	1	12	13
Total	16	23	35	**74**

Tabel 4. shows that articles combining simulation with hardware-in-the-loop (HIL) or prototype experiments tend to exhibit higher average RRI scores than those relying solely on simulations. In particular, the proportion of studies classified in the "high" and "very high" RRI categories is noticeably greater for validation categories X6 = 2 and X6 = 3. This cross-tabulation pattern suggests that the inclusion of physical experimentation is generally associated with enhanced reproducibility readiness, especially when validation setups are described in sufficient technical detail.

Detailed documentation of experimental configurations, test scenarios, and measurement procedures contributes to more robust and transparent research practices by improving result traceability and facilitating independent verification. Nevertheless, several pure-simulation studies still achieve medium to high RRI, indicating that reproducibility does not depend solely on the presence of physical experiments, but rather on the overall completeness and clarity of system reporting and validation methods. Conversely, the existence of HIL- or prototype-based studies with low RRI values confirms that the use of sophisticated experimental platforms alone does not guarantee high reporting quality, reinforcing the notion that reproducibility is fundamentally determined by how research is documented rather than by the tools employed.

3.7 Synthetic Discussion

Overall, the results above illustrate that reporting practices for systems, validation methods, and performance metrics in DSC research on DC microgrids exhibit varying levels of reproducibility readiness, with a predominant tendency toward medium and low categories. Although most articles report system configurations in considerable detail (Y1 is relatively high), weaknesses in validation methods (Y2) and performance metrics (Y3) make many studies difficult to replicate independently.

The combination of poorly documented validation scenarios, partially or non-quantitative performance metrics, and significant variability in validation methods creates a gap between algorithmic innovation and reproducibility readiness. In other words, many articles propose interesting control ideas but do not yet provide sufficient "technical trace" for other researchers to follow and verify their results.

These findings are consistent with concerns raised in the literature regarding the reproducibility crisis and the need for cultural shifts toward stronger open science practices, including in engineering disciplines [26]–[28]. On the other hand, the presence of a number of articles with high and very high RRI scores shows that good reporting practices can be achieved without sacrificing novelty, as long as researchers pay special attention to system transparency, experimental documentation, and performance metric reporting.

In the next section, these findings will be further analyzed from the perspective of research ethics and scientific responsibility, with reference to principles emphasized in the Research Ethics and Publication course, followed by practical recommendations for researchers, journals, and institutions working in the field of power systems and microgrid control [26], [29], [30].

4. Ethical Implications and Recommendations

4.1 Reproducibility as a Research Ethics Issue

The analysis in Chapter 3 shows that reporting practices in DSC research on DC microgrids are at varying levels of reproducibility readiness, with a dominant tendency toward medium and low categories. Although most articles report system configurations in sufficient detail (high Y1), weaknesses in validation methods (Y2) and performance metrics (Y3) make many studies difficult to replicate independently.

From a research ethics perspective, this situation cannot be viewed merely as a "technical limitation," but touches the core of scientific integrity. The National Academies report stresses that lack of reproducibility—due to poor documentation, lack of accessible data and code, or non-transparent methodology—can erode public trust in science and hinder the advancement of knowledge [26]. Similarly, the discourse on the replication crisis across disciplines shows that inadequate reporting practices are among the main causes of replication failures [27].

The open science movement views reproducibility as part of the moral obligation of researchers to make their work scrutinizable and testable by the scientific community [27], [28]. In electrical engineering and power systems, meeting this principle means providing sufficiently detailed system descriptions, validation procedures, and evaluation metrics so that other researchers can: (1) understand the assumptions and limitations of the study, (2) reconstruct the model and test scenarios, and (3) compare new approaches with previous methods in a fair manner.

Thus, the finding that many DSC DC microgrid articles still have limited reporting of validation methods and performance metrics indicates a gap between the ideal ethical standards (as formulated in responsible and ethical conduct of research frameworks and open science guidelines) and actual practice in the field [26]– [30]. Improving reproducibility in DSC research requires structural changes at multiple levels. Educational institutions should prioritize reproducibility training, and journals should enforce reporting standards that mandate transparent documentation of system configurations, validation methods, and performance metrics. These changes will foster a research environment where transparency and reproducibility are integral to the scientific process.

4.2 Ethical Analysis of the Findings

Transparency and Scientific Accountability

The principle of transparency requires that scientific procedures, data, and analyses be presented in a way that allows others to examine them. In this study, high Y1 scores show that DC microgrid system configurations are relatively well reported. However, low Y2 and Y3 scores in many articles indicate that the validation workflow and how control success is measured are not as transparent as the system model itself.

Ethically, when an article claims that a proposed method is “faster,” “more stable,” or “superior” but is only supported by qualitative plots without clear metrics (Y3 = 0), readers lack a solid basis for assessing the truth of such claims. This weakens scientific accountability because authors do not fully provide evidence that can be independently re-tested. In the long term, such practices can proliferate “superiority claims” that are difficult to verify and blur the knowledge landscape in DSC DC microgrid research.

Justice and Social Responsibility

DSC research on DC microgrids does not end at the simulation stage; its results are potentially applied to real power systems supplying electricity to campuses, industrial areas, or communities. If adopted control designs are based on studies that cannot be reproduced (because system and validation details are not adequately reported) there is a risk that technical and investment decisions are made on shaky evidential grounds.

From an ethical standpoint, this relates to the principles of beneficence and justice: implemented technologies should maximize benefits and minimize risks to users, and should not disadvantage certain parties due to decisions based on weak scientific evidence. Transparent reporting and reproducibility are therefore means of ensuring that DSC technologies used as references have undergone a trustworthy scientific evaluation process.

Professional Integrity and Publication Culture

The analysis in Chapter 3 shows that there are pure-simulation articles with high RRI, and there are also HIL/prototype-based articles with low RRI. This indicates that the main problem does not lie in "how sophisticated" the tools are, but in the researchers' commitment to documenting their work honestly, completely, and consistently.

The literature on responsible conduct of research places reporting integrity alongside issues such as plagiarism, fabrication, and falsification [26], [29], [30]. Although shortcomings in reproducibility do not automatically imply serious violations like fabrication, a systematic pattern of inadequate documentation can be seen as a form of professional negligence that needs to be addressed through changes in research culture and publication policies.

In the context of the Research Ethics and Publication course in Electrical Engineering/Informatics programs, these findings can be read as a reflection that the research community (including lecturers and students) needs to take reproducibility more seriously as an indicator of scientific quality, rather than treating it as a cosmetic addition in the methodology section.

4.3 Recommendations

Based on the empirical findings and ethical analysis above, this section presents recommendations addressed to several stakeholders: researchers, journals and reviewers, educational/research institutions, and the research and industrial communities involved in DC microgrid development.

Recommendations for DSC Researchers on DC Microgrids

1. Use system and validation reporting checklists:
   - Prepare appendices or dedicated tables summarizing system configurations (topology, types and numbers of DERs, loads, key converter and line parameters) for each case study.
   - Explicitly describe test scenarios (e.g., load changes, plug-and-play events, voltage disturbances) along with key parameters such as simulation duration, sampling time, and initial conditions.
2. Report quantitative and consistent performance metrics:
   - At minimum, include metrics such as settling time, overshoot, current-sharing error, and steady-state voltage deviation, and explain how these metrics are computed.
   - Avoid qualitative claims without numerical support; every statement such as "better" or "faster" should preferably be backed by numerical comparison with reference methods.

3. Document research artifacts as openly as possible:
   - Provide simulation code, model files, or at least pseudo-code and block diagrams detailed enough for other researchers to reconstruct the algorithm.
   - If full release of data or code is impossible (e.g., due to industrial constraints), researchers can provide synthetic data or generic test scenarios that represent real conditions, while clearly stating the limitations [27], [28].
4. Educate students and collaborators about reproducibility:
   - Normalize the use of version control, structured experimental documentation, and systematic parameter logging as part of supervising final projects and theses.

Recommendations for Journals and Reviewers

1. Require a data/code availability statement: Article templates can include a dedicated section that explains the availability of data and code, including reasons if certain artifacts cannot be shared. Such policies are already common in many international journals and are aligned with open science principles [27], [28].
2. Promote reporting standards for microgrid studies:
   - Publishers and professional associations can develop reporting guidelines for simulation and experimental microgrid studies (e.g., a minimum list of system parameters, test scenarios, and performance metrics that must be reported).
   - Reviewers can treat the completeness of system and validation reporting as a major review criterion rather than a secondary concern.
3. Recognize replication and critical evaluation studies:
   - Journals should provide space for articles that explicitly perform replication or comparative evaluations of existing DSC methods, as long as they are conducted with strong methodology. This helps build a culture in which reproduction and verification are recognized as legitimate scientific contributions, not merely "technical work" without publication value [26], [27].

Recommendations for Educational and Research Institutions

1. Integrate reproducibility into the curriculum: Research methodology and research ethics courses can include modules on reproducibility, open science, and research data management, with practical assignments that require students to document their experiments comprehensively.
2. Provide supporting infrastructure: Institutions can provide internal repositories or integration with public services (e.g., OSF, Git hosting) for

storing and sharing research data and code, with clear policies on ownership and access.

3. Make reproducibility a research performance indikator: In internal grant evaluations or research assessments, institutions can include indicators such as data/code availability, methodological documentation quality, and evidence of reuse as part of research output quality, rather than relying solely on publication counts and impact factors.

Recommendations for the Research and Industrial Community

1. Collaborate on open benchmarks and platforms:
   - The DSC DC microgrid community can develop agreed-upon standard test systems (benchmarks) along with datasets and scenarios, so that different control approaches can be compared on a common basis.
   - Industry partners can support these initiatives by providing anonymized or synthesized data that preserve confidentiality while still being useful for reproducibility.
2. Design research contracts that support constrained but meaningful openness: In joint industry–academia projects, contracts can be structured so that some artifacts (e.g., generic models, control structures, or synthetic data) remain publishable for scientific purposes, with clear arrangements for intellectual property rights. This accommodates the principle "as open as possible, as closed as necessary" [28].

4.4 Practical Implementation Framework

As a summary, **Tabel 5** presents a simple implementation framework linking actors, key actions, and expected ethical impacts.

Tabel 5. Implementation framework for improving reproducibility in DSC

Actor	Key Actions	Expected Ethical Impact
Researchers	System & validation reporting checklists; clear performance metrics; sharing code/data where possible	Transparency, accountability, and ease of verification
Journals & reviewers	Data/code availability policies; reporting standards; appreciation of replication studies	Improved methodological and reporting quality in publications
Educational/research institutions	Reproducibility modules in the curriculum; research repositories; supportive performance indicators	A research culture that upholds integrity and open science
Research community & industry	Development of open benchmarks; research contracts that support constrained openness	Technically and ethically well-grounded technical and investment decisions

This framework shows that improving reproducibility is not solely the responsibility of individual researchers, but requires structural changes at the levels of journals, institutions, and the broader research ecosystem [26]–[30]. Gradual implementation, starting from simple steps such as reporting checklists and internal repositories, can already have a significant impact on the quality and integrity of DSC research on DC microgrids.

Thus, Chapter 4 underscores that the ex post facto findings presented in this article are not only methodologically meaningful, but also carry a normative message: the electrical engineering research community has a collective responsibility to ensure that proposed control innovations are not only "novel" and "advanced," but also scientifically and ethically defensible.

5. Conclusion

This study conducted an ex post facto analysis of 74 articles on distributed secondary control (DSC) in DC microgrids with the aim of evaluating system configuration reporting, validation methods, and performance metrics from the perspective of reproducibility readiness. To this end, a Reproducibility Readiness Index (RRI) was developed by combining three main indicators and examining the relationships between RRI and several technical and publication-related variables.

The analysis shows that most articles fall into the medium and low RRI categories, with only about one third achieving high or very high levels. In particular, almost all articles report system configurations in sufficient detail (Y1 is generally high), but there remain substantial weaknesses in the reporting of validation methods (Y2) and performance metrics (Y3). Sparse descriptions of platforms and test scenarios, together with a dominance of qualitative performance claims without clear quantitative metrics, make many studies difficult to reproduce independently, despite offering interesting algorithmic innovations. Cross-tabulation analysis also indicates that the presence of HIL or prototype experiments tends to correlate with higher RRI, but does not automatically guarantee reproducibility when experimental documentation remains insufficient.

From a research ethics standpoint, these findings reaffirm that reproducibility is not merely a technical issue, but an integral part of scientific integrity, transparency, and researcher accountability. DSC research on DC microgrids may be adopted in real, safety-critical power systems, so design decisions based on poorly documented studies risk leading to technical and investment decisions that are difficult to justify. This article contributes by: (i) providing an empirical picture of current reproducible research practices in the DSC DC microgrid domain, and (ii) formulating ethical recommendations and an implementation framework for researchers, journals, institutions, and industry to strengthen open science and reproducibility within the power engineering research community.

This study has several limitations, including the fact that RRI assessment relies entirely on information written in the articles (without model re-implementation) and that ordinal coding was carried out by a single rater. Future work could extend the analysis by involving multiple coders to increase reliability, conducting empirical replications of selected representative DSC schemes, or comparing reporting practices in other domains such as AC microgrids, smart grids, or AI applications in power systems. Nevertheless, the findings are expected to trigger critical reflection among electrical engineering and informatics researchers and students on the importance of designing and reporting research not only so that it can be published, but also so that it can be re-tested, trusted, and ethically beneficial for the development of science and society.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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