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TOPICAL REVIEW

A Comprehensive Review on Recent Developments of Hosting Capacity Estimation and Optimization for Active Distribution Networks

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ABSTRACT Recently, several types of distributed energy resources (DERs) have been developed to reduce the environmental impact and support the global demand for electrical energy. However, the continuous penetration of the DERs into modern power systems (MPSs) may cause several adverse impacts in terms of operation performance indices (PIs) and power quality issues, especially in low-voltage distribution systems (LVDSs). To cope with these serious impacts and achieve optimal control, the hosting capacity (HC) of DERs must be accurately estimated and optimally optimized. However, it requires an extensive communication infrastructure, which is hardly offered without clear financial benefits. In this regard, this article investigates the historical developments of HC definitions as well as the recent developments in terms of operational performance indices, and estimation methods for active distribution networks (ADNs) with the high-penetration level existence of the DERs, energy storage systems (ESSs), electric vehicle (EV) charging systems, sector coupling, hydrogen technologies, and multi-carrier energy systems (MESs) to deal with electrical, thermal, and cooling demands. In this regard, this review article is intended to exhibit an appropriate reference for comprehensive research trends in HC estimation and optimization based on ADNs. Additionally, it involves and covers most current research HC topics in detail compared to other published review articles. Moreover, the authors deliberate the recent approaches for evaluating and improving the HC, especially concerning data-driven methods, with the aid of various software for simulating real systems. Moreover, modern research trends and main factors of MPS operations are deliberated with current energy market developments. Also, prominent challenges, current status, and future aspects are discussed.

INDEX TERMS Hosting capacity, distributed energy resources, energy storage systems, electric vehicles, active distribution networks.

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I. INTRODUCTION

A. BACKGROUND

Owing to the increased global demand for electrical energy, it is required to utilize alternative energy sources to conventional sources to reduce their bad environmental impacts. So, the penetration of distributed energy resources (DERs) for instance; renewable energy sources (RESs), especially solar photovoltaics (PV), increases periodically in low-voltage distributed systems (LVDSs) [1]. Regarding the global statistics, energy consumption shows a gradual increase from around 112 petawatt hour (PWh) in the year 2000 to 159 PWh in 2021, also observing energy consumption decline in 2020 to amount of 151 PWh due to the coronavirus pandemic and global lockdown policy [2]. Looking specifically at Fig.1, it is clear that most energy consumption depends mainly on fossil fuels such as gas, coal, and oil besides small contributions of RESs and other sources to cover the global energy demands. In [3], the statistics depict that only energy amount 28 PWh was used for electricity production globally with a percentage of 18.5% of total energy consumption in 2021. In 2022, the various RESs generated about 52% of the total electricity production and are expected to increase by 20.6 % in 2050 [3], [4]. China became the first leading country to implement large stations' capacities of RESs achieving about 1.16 terawatts. In turn, the USA came in the second rank with 352 gigawatts while the remaining counties contributed 91.25% of total electricity production from RESs [5]. Consequently, it is critical to reduce energy consumption from fossil fuels and provide alternative sources with low carbon emissions and harmful impacts on our environment.

Worldwide, the penetration of various DERs is being increased significantly which has several impacts on the modern power systems (MPSs) [6]. So, it is essential to be regulated to avoid deteriorating the power quality (PQ) of the active distribution networks (ADNs). The DER penetration in the ADNs can be classified into three stages based on the ratio of DER production to power consumption namely as low, moderate, and high levels [7]. At a high level, the negative impacts of the excessive generation of DERs can be worryingly observed by system operators in terms of ADNs performance and quality deterioration, voltage unbalance, losses, harmonics, and distribution line ampacities. So, it is essential to preserve the adverse impacts under acceptable limits. Thus, the term of the hosting capacity (HC) of ADNs is extensively utilized, which is primarily originated in 2004 by Bollen et al. [8]. As depicted in Fig. 2, the HC concept can be defined as the maximum generation of DERs that can be accommodated without endangering the ADNs' PQ and reliability [7]. By applying the HC concept, the optimal amount of DERs, which can be integrated into the ADNs without adverse impacts, is critically specified for current power consumption and future ADN support with predicted expansions [9]. In this regard, several approaches have been established to recognize and optimize the HC of the ADNs and study the comprehensive influences of different parameters and considerations. Moreover, other studies elaborated on the HC enhancement techniques and the suitable tools and software to find the accurate HC value, as detailed in [9], [10], [11], [12], and [13]. These studies considered only the impact of increased penetration level-based PV systems neglecting other influences of applied DERs in ADNs.

B. MOTIVATION AND RESEARCH GAP

For ADNs, the integration of several types of DERs (PV, wind turbine (WT), thermal distributed generators (DGs, etc.) has been significantly increased with the presence of electric vehicle (EV) charging stations and various types of energy storage systems (ESSs), that have adverse influences on the PQ indices [7]. As well the concept of energy hub (EH) has been extensively applied using multi-carrier energy systems (MESs) to support the electrical, thermal, and cooling demands [14]. All of these advanced components essentially require both distributed smart meters and powerful communication systems that should be implemented in ADNs to accomplish the effectiveness of centralized control and achieve the balance between generation and consumption without violating the technical and economic constraints [15]. By using the smart meters, huge collected data from measurement devices are attained which are required to implement extensive communication infrastructure to treat the increased availability of collected data for optimal control, performance prediction, and cost-effective management of ADNs [16]. Therefore, it is essential to extend the HC concept for all advanced power system components in order to specify their maximum allowable integration into the ADNs while conserving the acceptable operation constraints of performance indices (PIs). In addition to dealing with the obstacles of extreme availability data from smart meters for achieving complete system controllability with using limited communication infrastructure. According to published articles, most of the existing review articles fail to elaborate on all these raised prominent points in detail and their impact on HC calculations and the operation performance of ADNs.

Most articles acknowledged that the HC research trends associated mainly with the PVs only neglect other important aspects, and other recent technologies. The first missing aspect is the consideration of various types of DERs, in addition to the role of various types of ESSs, and especially EVs, which have great impacts on modern ADNs. The second aspect is the lack of a unified definition of HC that considers diverse factors in MPSs. The next aspect is the assessment of HC by empowering new PIs in ADNs, which requires more investigation. Furthermore, the consideration of the rising role of hydrogen technologies will have a great impact on the HC task. Accordingly, the next missing aspect is to review the recent trends in such hydrogen technologies. Besides, the contribution of energy management systems and EH with various MESs considering various demand types (cooling, thermal, and electrical loads), requires more investigation.

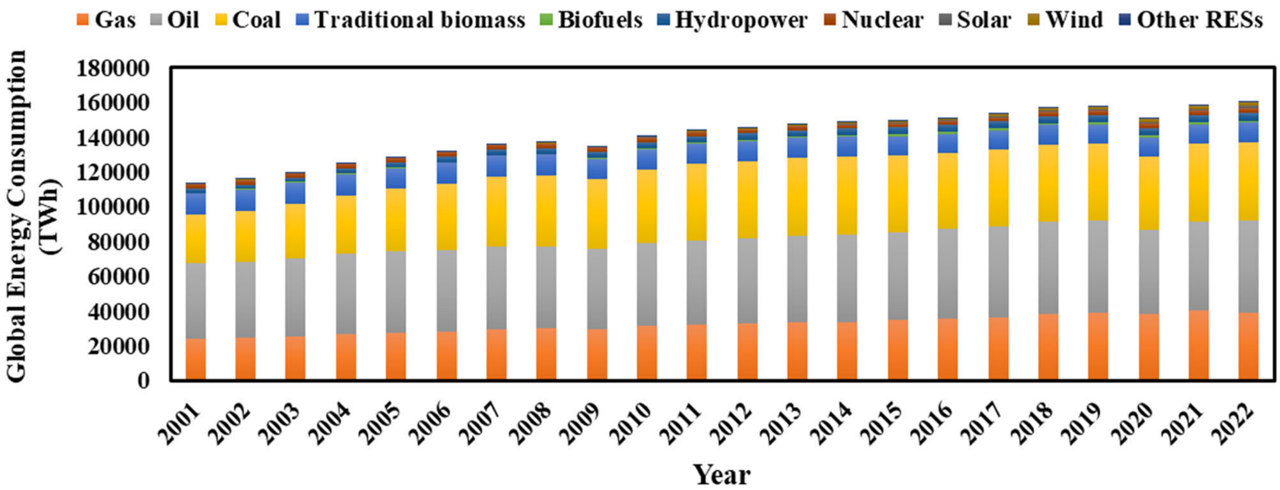

FIGURE 1. Global direct primary energy consumption [2].

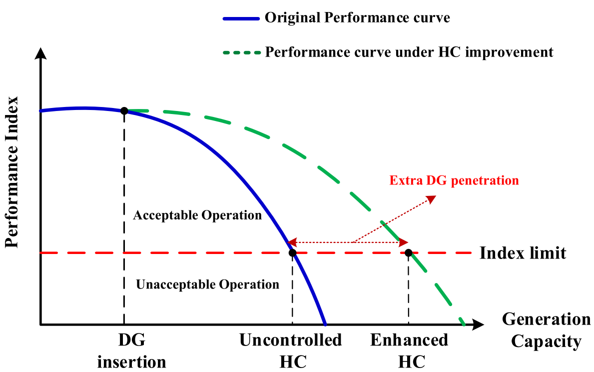

FIGURE 2. General HC concept.

Finally, the role of the following terms is required to be highlighted for HC improvement, including, energy forecasting, communication infrastructure, networks' configuration, sector coupling, and energy markets linked with the HC assessment. Thus, this article covers most of the important recent HC research topics in detail compared to other published articles.

C. CONTRIBUTIONS

To cover the abovementioned gaps, this article presents a comprehensive analysis of the HC research trends in terms of various objectives and contributions which can be summarized as follows:

- ✓ Declaring the state of the art of the HC concept and definitions considering various DERs, EVs, and ESSs in addition to their impacts on the modern ADNs based on their uncertainties.
- ✓ New HC definition is stated in terms of various significant factors and elements found in MPSs. Besides signifying the most vital PIs for HC assessment including newly applied PIs in MPSs such as risk index (RI).
- ✓ Indicating the various HC estimation approaches especially the data-driven methods, supported with comparison, discussions, recommendations, and the applied tools and software.
- ✓ Identifying various HC enhancement techniques and the application of modern techniques such as hydrogen technologies. Also highlighting the role of energy management systems (EMSs) in HC enhancement with the contribution of EH with various MESs to respond to the energy demands (cooling, thermal, and electrical loads), as well as the EVs and their charging stations.
- ✓ Discussing the various aspects related to the modern power grids such as emerging grids, risk and security assessment, communication infrastructure, and loss sensitivity analysis.
- ✓ Mentioning some of the real networks' configuration, and energy markets associated with the HC concept.
- ✓ Deliberating perspectives for prominent challenges and current status following future technologies of HC approaches as research trends: perceptions and outlooks.

D. ARTICLE ORGANIZATION

The remainder of this article is summarized as section II states the search methodology of historical developments of the HC concept that is comprehensively investigated in section III. Section IV discusses the various PIs applied for assessing and calculating the HC using conventional, modified, and data-driven approaches that are elaborated respectively in section V. As a result, section VI presents the used tools and software frameworks for calculating the HC before investigating the HC enhancement techniques in section VII. The new concepts applied in the MPSs to increase their sensitivity and reliability are discussed in section VIII. Followed by deliberating the energy markets, challenges, and future

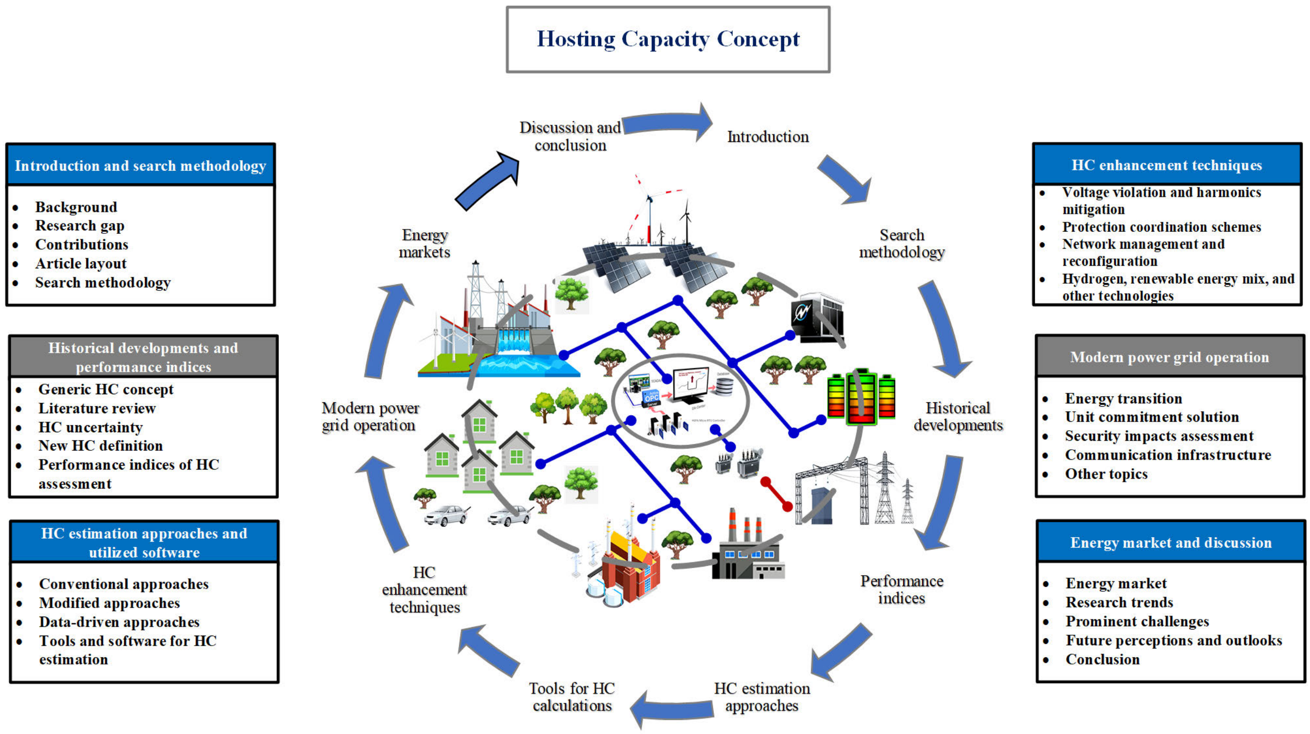

FIGURE 3. Article layout.

aspects in section IX, and section X, respectively. Finally, the work conclusion is given in section XI. Moreover, Fig. 3 depicts the article layout with the main contributions.

II. SEARCH METHODOLOGY

The search methodology followed in this article for comprehensive analysis of HC research trends, is dependent on both indexed articles (journal or conference proceedings) and books on Scopus and Web of Science databases using IEEE Xplore, Google Scholar, and ScienceDirect websites (considering only English publications). The utilized keywords were (hosting capacity, DER, renewable energy, PV, EV, HC assessment, Performance indices, HC estimation approaches, HC enhancement techniques, machine learning (ML), and future technologies) which in turn generated over 1757 document results. Hence, the search methods can be concluded as:

- Initial search results: a total of 1757 document results were attained using IEEE Xplore, Google Scholar, and ScienceDirect.
- Initial search results assessment: a total of 1115 documents were evaluated based on the article title, abstract, keywords, article construction, contribution, results, and conclusion, which were associated with the main topic.
- Rigorous search results refinement: a total of 660 were considered based on the publishers, impact factors, and significant coherence.
- Final procedure: The most recent and relevant total of 350 published documents were selected over the past 5-year period.

Moreover, the coherence among various terminologies, aspects, and research keywords associated with the HC concept is investigated based on the Scopus database in Fig. 4, using the VOS viewer platform [17]. Hence, 6 data clusters are depicted to make the complete picture of the HC research trends, which can be summarized as follows;

- Cluster 1 (Yellow): considering the HC calculation methods and their relations with electrical load dispatching and hydrogen storage elements.
- Cluster 2 (Green): performing relations among performance indices, HC assessment methods, and ESSs.
- Cluster 3 (Cyan): depicting the research trend of PQ improvement, especially harmonic analysis.
- Cluster 4 (Blue): stating the various HC enhancement techniques and their relations to the penetration level.
- Cluster 5 (Purple): declaring the associations among economic solutions, and energy market, and EHs.
- Cluster 6 (Red): investigating the impacts of EV charging systems, and virtual power plants on microgrids and ADNs related to energy management and forecasting using the ML techniques.

Besides the conventional research trends of the HC concept, the high-penetration level of DERs, and the gradual serious impacts new ESSs, EV charging systems, and MESs to deal with energy demands, are considered. Further, the data-driven

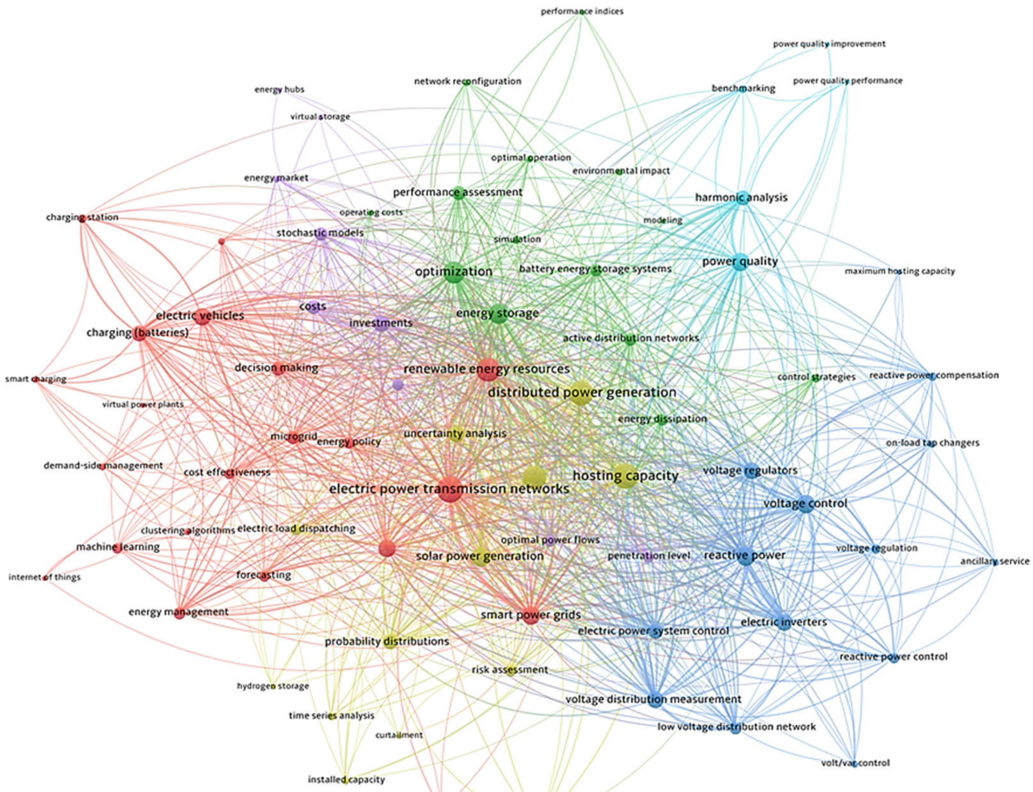

FIGURE 4. Historical development presentation of HC concept using VOSviewer platform.

approaches are gradually applied to EMSs to enhance and control the HC of MPSs and to forecast optimal operation.

III. HISTORICAL DEVELOPMENTS OF HC CONCEPT

The HC concept was first proposed by Math Bollen in 2004 [8] as a vital approach to deal with the various impacts on the utility grid (UG) during the vastly increased penetration of the DERs [7] which also highlighting the technical restrictions influenced directly on both system operators and customers. In this section, general HC definition, HC uncertainty and HC coefficient (HCC) are discussed followed by a comprehensive analysis of the HC developments based on various published review articles. From these sub-sections, the authors propose a new definition of HC for ADNs.

A. GENERIC HC CONCEPT

Several studies investigated the HC as the maximum specified amount of DERs can be integrated into the UG without any PIs deteriorations or interruptions. Others in [11] and [18] stated that the HC definitions are investigated using various references in many aspects like peak load, transformer rating, customers' PV systems, active power, energy consumption, and roof-space PV systems. The authors concluded that the references values and limiting factors are variable standards that linked directly to the HC calculations based on distribution system operators (DSOs') rules of thumb for DER coupling, as summarized in Table 1.

By using peak feeder load as a restricted reference, the authors in [19], [20], and [21] concluded that the HC equals the ratio of the maximum capacity of PV implementation to the peak load demand. With restricting the voltage deviation $\pm 5\%$ of nominal value, the authors in [19] estimated the maximum PV HC of connected feeders by 97.3% of peak load using various energy management approaches on IEEE 123-bus system. To maintain the voltage deviation within the acceptable limit, both deterministic and stochastic HC methods were employed based on the amount of PV units connected to the customer's feeder. The estimated HC was about 45%-70% of the feeder's design load associated with the PV generation probabilistic [20]. Another new possibilistic method was applied with the accurate membership function based on load demand in order to assess the HC under uncertainties of both PV outputs and peak load demand. The HC was estimated in IEEE 34-bus system by 2–10% of PV penetration higher than conventional methods [21].

Regarding to the transformer rating constraint, the maximum HC should equal the total amount of PV output as a ratio to the transformer capacity [22], [23], [24], [25]. Hence, the improved HC was conducted by 20% to 35% of the transformer rating, using both the optimal residential demand response program (DRP) and on-load tap changer (OLTC) transformers based on the Australian LV network [25]. For Finnish and real LVDSs, the Monte Carlo (MC) and other simulation methods were applied in [22], [23], and [24] to

TABLE 1. Various international DSOs' rules of thumb for DER coupling [7], [11].

Country	Limiting Constraints: TR	CB rating	SCC	FL	DSO rules
Belgium	✓				DERs rating < MV/LV transformer capacity
Canada				✓	DERs rating < 50% → 100% of feeder capacity OR DERs rating < 15% of annual FL
China			✓		DERs rating < 10% of SCC at PCC
Czech	✓				DERs rating < MV/LV transformer capacity
Italy	✓				DERs rating < 65% of MV/LV transformer capacity
Portugal	✓				DERs rating < 25% of MV/LV transformer capacity
South Africa	✓	✓		✓	• TR: DERs rating < 50% of MV/LV transformer capacity • CB rating: DERs rating < 25 % of LV feeding CB rating for shared feeder OR DERs rating <75 % of LV feeding CB rating for dedicated feeder • FL: DERs rating < 50% → 100% of feeder capacity OR DERs rating < 15% of annual FL
South Korea	✓		✓		• TR: DERs rating < 20% of MV/LV transformer capacity • SCC: DERs rating < 15% of the thermal limit of the affected feeders
Spain	✓				DERs rating < 50% of MV/LV transformer capacity
USA			✓	✓	• SCC: DERs rating < 10% of SCC at PCC • FL: DERs rating < 50% → 100% of feeder capacity OR DERs rating < 15% of annual FL

*TR: transformer rating; CB: circuit breaker; PCC: point of common connection; SCC: short circuit capacity; FL: feeder load;

analyze the increased HC as a function of OLTCs, Battery ESSs (BESSs), and other reactive power control (RPC) equipment. According to the number of customers, some authors defined the HC as a ratio between the number of DSOs who installed PV and the total number of DSOs. The estimated number of customers that were badly influenced by the voltage deviation was reduced from 118 to about 9 customers on 100% PV penetration by adopting (OLTC) transformer, and capacitor banks with MC analysis based on a real UK residential LV network [26], [27].

Another small percentage of published articles around (14% of total articles) state the HC concept relative to the actual load's active power, the roof-space availability, and the annual energy share of PV generation units. The increment HC is determined as a percentage of the roof space that can be exploited to implement PV arrays to all roof space of "feeder-connected households". Hence, the authors in [28] represented the most economical solution for increasing the penetration by 30% to 70% without exceeding the PIs of the rural LVDSs using RPC and other methods based on the roof-space of customers' households terms. Whereas others defined the HC as a proportion of PV output (active power) to the total energy consumption or load's active power. As stated by [29], the voltage stability could be maintained at 10% - 30% PV penetration levels for R/X ratio LVDSs, based on the load's active power, with the capability to improve the HC using PV inverter reactive power support and other ancillary services. To cope with the increased consumption, the optimal quadratic control schemes were utilized in order to raise the HC of rooftop PVs in LVDSs with the aid of various HC improvement approaches [30].

The previous definitions are associated with the PV penetration into the ADNs only; however, various articles consider the penetration level of other DERs, EVs, and ESSs in cooperation with the PV systems related to the recent research trends for instance in [31], [32], [33], [34], [35], [36], and [37]. The voltage stability was investigated due to the integration of wind farms by considering the stochastic behaviour and their impacts on the UG as well as proposing a new control method to withstand the acceptable voltage limits on the IEEE-57 bus system [31]. To diminish the increased involvement of DERs in the ADNs, various ESSs are applied to sustain the best operation and PQ by optimizing their best location and capacity as reviewed in [38] and [39]. On the other hand, the negative impacts of the increased EV number can be eliminated using a suitable energy management method in collaboration with PV systems and other ESSs. Further, EVs can be deployed with various MESs to enlarge the operator's profit and minimize CO_2 emissions which have been recognized as a promising research trend recently [32], [33]. Another efficient probabilistic energy management strategy is used with concerns of EV charging systems, ESSs, DRPs, and both smart meters and transformers with robust communication systems [34], [35]. To accomplish reliability and high operation quality in MPSs, robust communication networks with the help of data-driven methods, should be installed for smart monitoring and complete control of all integrated systems such as EVs, ESSs, DERs, smart meters.....etc; as discussed in [36] and [37]. As previously reviewed, it is clear that the HC definitions differ based on various aspects of MPSs. So, it is important to involve new HC concepts associated with these modern technologies.

B. LITERATURE REVIEW

To follow the historical developments of the HC concept, various previous studies are considered, which were published to propose the outlines of the HC concept in terms of many research objectives such as HC calculation methods, techniques for HC enhancement...; based on how to contain the presentation of research objectives according to $R1 \longmapsto R8$, as summarized in Table 2. In which the prominent articles mentioned in the literature review are chronologically organized over the past 18 years. Most mentioned articles in literature review investigated some of the provided research objectives especially HC estimation and enhancement aspects. Moreover, as acknowledged, no unique review article covered all the research objectives in detail. Therefore, this article will cover all research objectives related to the HC concept besides presenting new research trends that have recently been applied. Hence, this article proposes an inclusive review of the HC concept based on the historical developments, continuous impacts of high-level DERs and ESSs integration into ADNs, calculation and assessment approaches, data-driven methods, applied software, HC enhancement methods, energy markets, challenges, and future aspects. In addition to discussing the effects of the DERs and ESSs on the energy management strategies during stochastic integration of MESs to supply the thermal, cooling, and electrical energy demands.

C. HC UNCERTAINTY

According to the stochastic nature of DERs, it is critical to consider the various sorts of uncertainties during HC calculations in the LVDSs. Many articles concluded that the uncertainties can be classified into DERs' uncertainties or consumer and feeder uncertainties [11], [40]. The DERs' uncertainties based on Electric Power Research Institute (EPRI), include the size and the location of the DERs, connection type ($1\varphi or 3\varphi$), DERs connection on the distributed phase, number of units, and different scenarios of energy generation. Alternatively, the consumer and feeder uncertainties specialize in load profiles and type, transformer capacity and voltage, as well as consumer location from the supplied feeder. In addition, other uncertainties should be considered when exhibiting HC estimation in MPSs for instance; ESSs' capacity, intermittent nature of EVs or RESs, the protection devices, type of converters (conventional or smart), collected measurements of smart meters, voltage equipment restrictions, communication infrastructure, and applied standards. After applying these uncertainties, the calculated HC is not a unique value but will be multiple values depending on the number of contributed uncertainties to the HC calculations or optimization problem.

D. NEW HC DEFINITION

From the above-mentioned discussions, the authors can state a new comprehensive HC definition for MPSs as follows;

(Total DERs, and ESSs that can be accommodated on the ADNs without any violation in various performance indices and exclusive of requiring network upgrades for MPSs, using limited communication infrastructure systems, in the presence of EV charging systems and MESs to deal with Electrical, thermal, and cooling demands)

IV. PERFORMANCE INDICES OF HC ASSESSMENT

With regards to the HC definition, it is essential to specify the limiting constraints and impact factors of the PIs for accurate HC calculation and optimization due to the increased penetration of the DERs into the MPSs, as explained in [7], [11], [12], and [18]. In this section, a comprehensive overview of various PIs for HC evaluations and their limits according to applied standards, are investigated as follows.

A. VOLTAGE VIOLATION PROBLEMS

The most prominent PI to assess the PQ of LVDSs is system voltage which can perform several issues as follows;

1) VOLTAGE LEVEL CRITERIA

The voltage level may be under or above the acceptable limit as a function of the consumed active power, and increased DERs penetration. In the peak generations, there is an unbalance between the power generation and consumption causing a reverse power flow which leads to voltage rise issues. However, in off-peak load periods, under-voltage problems come into the picture. So, it is critical to specify the voltage level (ΔV) using the following approximated equation [58];

$$\Delta V \cong \frac{(P \times R) + (Q \times X)}{|V_n|} \tag{1}$$

here P and Q are the active and reactive powers as a function of system resistance (R) and reactance (X), respectively. So, implementation of voltage regulators with voltage techniques is crucial besides being ready to provide reactive power by governing the converters and flexible AC transmission system (FACTS). For proper voltage regulating, the five voltage standards globally applied named "European Standard EN-50160 ($\pm 10\%$ of nominal voltage (Vn)), German Standard VDE-AR-N 4105 ($+3\%$ of Vn), American Standard ANSI C84.1 ($\pm 5\%$ Vn), Australian Standard ($-6/+10\%$ Vn), and Canadian Standards Association (CSA) ($\pm 6\% Vn$)" [18]. For example, the authors in [59] conducted their HC assessment with the specified voltage rise ($\pm 10\%$ Vn) and unbalanced (2% Vn) limits for the Danish LVDSs under the connection of OLTC and PV inverters.

2) VOLTAGE UNBALANCE CRITERIA

Owing to the load diversity and various connection types ($1\varphi or 3\varphi$), there will be unsymmetrical load profiles that cause a voltage unbalance issue which is the proportion of the negative sequence voltage component to the positive sequence voltage component. Hence, the global standards have identified acceptable voltage unbalance in LVDSs within 1-3% of nominal voltage. The voltage unbalance factor (VUF) can be determined by the following equations:

$$VUF\% = \frac{V_2}{V_1} \times 100 \tag{2}$$

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_C \end{bmatrix} \tag{3}$$

TABLE 2. Literature review of the most prominent articles related to the HC concept.

Ref.	Year	Research Objectives								Article contribution
		R1	R2	R3	R4	R5	R6	R7	R8	
[41]	2005	✓	×	×	×	×	×	✓	×	By using the HC concept, the European Distributed Energy Partnership project (EU-DEEP) proposed a unique method (DER aggregation method) to evaluate the UG performance during the increased penetration of the DERs in the low and medium voltage (LV and MV) distribution networks over the 10-year time interval from 2010 to 2020.
[42]	2006	✓	✓	×	×	×	×	×	×	Constructing a semi-definite association between the degree of harmonic distortions and their effects on the HC in the presence of the high-level penetration DERs.
[43]	2011	✓	×	×	✓	✓	×	✓	✓	Investigated the influences of various DERs on the UG performances and the PIs limits to keep safe operation.
[44]	2012	✓	✓	✓	×	×	✓	×	✓	Studied the performance limits in Swedish distribution networks using the HC concept via "(simulation, modelling and calculation)" during the high-level penetration of the solar PV substations. The study outlined the significant impacts of surpassed performance limits and the pivotal performance limits should be monitored during calculating the HC such as overvoltage. Which can be diminished and enhanced by the HC using RPC techniques and transformer tap changer alteration.
[45]	2014	✓	✓	✓	✓	×	×	×	×	To enhance the HC, the outcomes of the CIGRE research group specified the performance limits which influence the UG stability. Also presenting the HC assessment methods of some international DSOs and their rules of thumb for DG interconnections.
[46]	2014	✓	✓	✓	✓	✓	×	×	✓	Investigated several HC improvement methods such as active power curtailment (APC), implementing energy storage units (battery, super-capacitor, EV, full cell), and modifying infrastructure of communication systems; on both theoretical and practical topics supported by practical case studies.
[47]	2015	✓	✓	✓	✓	✓	×	×	×	Studied the stochastic nature of the DERs' output power which influenced the control system operation in terms of the HC aspect. Also, formulated an optimization problem for HC estimation, evaluation, and improvement.
[48]	2015	✓	✓	✓	✓	✓	×	×	×	By evaluating the HC problem, various HC enhancement techniques were proposed based on RPC and cable reinforcement methodologies considering the various limits of the PIs such as overvoltage.
[49]	2015	✓	✓	✓	✓	×	×	×	×	Involved in the various HC approaches in terms of different performance indices. In addition to presenting the HC optimization and estimation methods.
[6]	2016	✓	✓	×	✓	×	×	✓	✓	Stated the various influences of high-level PV systems penetration based on voltage deviations and investigated the proper mitigation techniques to overcome these bad impacts and maintain the dominant operation of LVDSs.
[50]	2017	✓	✓	✓	✓	×	×	×	×	Proposed an assessment methodology of the HC estimation for ADNs based on the uncertainties of both DERs and connected loads.
[22]	2018	✓	✓	✓	×	✓	×	×	×	Applied the MC-based method for analyzing the HC based on real systems.
[51]	2018	✓	×	✓	×	×	×	×	✓	ML techniques, especially support vector machine (SVM), was used as a mean of grid classifications for HC estimation and enhancement.
[7]	2019	✓	✓	✓	✓	×	×	✓	✓	Studied the urgent impacts of the increased penetration of RESs into the UG and how to overcome them by applying the HC concept. This article investigated point by point the HC assessment, estimation, and optimization approaches in terms of real studied systems.
[52]	2019	✓	×	×	✓	✓	×	×	×	To maintain the power system stability and reliability during the increased integration of the DERs considering uncertain power generation, the authors investigated the state-of-the-art protection and voltage regulation systems to enhance the voltage profile and overall PQ.
[18]	2020	✓	✓	×	✓	×	×	✓	✓	In this review article, the HC definition, estimated values, evaluation parameters, limits, and enhancement methods were discussed with respect to the impacts of high-level PV systems integration into the UG.

TABLE 2. *(Continued.)* **Literature review of the most prominent articles related to the HC concept.**

[12]	2020	✓	✓	✓	×	×	✓	×	×	Besides studying the influences of high DERs and RESs penetrations into the UG and how to estimate the HC, it discussed the tools and their related software that are used for calculating the HC.
[9]	2020	✓	✓	✓	×	×	×	×	✓	Analyzed the fundamental three approaches for calculating the HC for LVDSs and comparing them with possible research trends.
[53]	2021	✓	✓	✓	✓	✓	×	×	✓	Stated the security impacts on modern UG due to the increased emerging of RESs by reviewing the ESSs developments as backup sources used in the UG based on 100% RESs. In addition to investigating assessment of PIs, voltage and frequency control schemes, optimization methods for optimal allocation of DERs, and enhancement UG operation to perform good PQ performance.
[54]	2022	✓	×	×	×	✓	✓	×	✓	Explained in detail the formworks' development of the deep-learning (DL) algorithms that contributed to dealing with complexity, nonlinearity, uncertainty, data diversity, and domestic observability of the modern ADNs due to the increased RESs integration into the UG. Along with, investigating the frequency analysis and control methods.
[55]	2022	✓	×	×	×	✓	✓	×	✓	Here, Artificial Intelligence (AI) techniques are used to evaluate the PQ of MPSs in the presence of various types of RESs by considering the harmonics and waveform distortion indices.
[40]	2022	✓	✓	✓	×	×	✓	✓	✓	Investigated the various approaches for estimating the HC of the LVDS based on the integration of the residential PV installations into the UG with a comprehensive comparison of them in a consistent manner using the definite real network.
[56]	2022	✓	✓	✓	✓	×	×	✓	✓	A comprehensive review of the HC estimation methods and enhancement techniques was presented based on industrial and practical projects considering new research trends.
[11]	2022	✓	✓	×	✓	×	×	✓	✓	Has similar contributions to Ref. [18].
[10]	2023	✓	✓	✓	✓	✓	×	×	✓	Proposed a comprehensive analysis associated with AL techniques as a significant tool for real-time estimation of the PQ factors and the HC forecasting due to the increased integration of the DERs in ADNs.
[13]	2023	✓	✓	✓	✓	✓	×	×	✓	In this article, the HC assessment and calculation methods were not only discussed but also the coordinated voltage control techniques using the Reinforcement Learning (RL) strategies were deliberated.
[57]	2023	✓	✓	✓	×	×	✓	×	×	In this article, not only the state of the art of both HC estimation methods and HC evaluation factors explained in detail, but also the approaches and tools for implantation of the HC calculations as a function of the amount of PV generations or EV charging, were deliberated.
This work	2023	✓	✓	✓	✓	✓	✓	✓	✓	This work presents a comprehensive review of the HC concept in terms of the historical developments, serious influences of high-level DERs and ESSs integration into ADNs, HC estimation and evaluation methods, implementation tools/software, improvement techniques, energy markets, challenges, and future aspects. Further, this article investigates the prominent role of not only PV systems but also the various types of DERs, EVs and ESSs in energy management strategies, especially in the existence of MESs to supply the thermal, cooling, and electrical energy demands. Moreover, the data-driven methods are disused as alternative solutions to conventional HC estimation methods. Finally, investigating the various perspectives of the MPS operation with the applications of new industrial technologies.

- R1: Impacts of high-level DERs and ESSs integration into the UG.
- R2: PIs of HC assessment.
- R3: HC estimation and optimization
- R4: HC enhancement techniques.
- R5: Operation of protection and control systems.
- R6: Tools/software for HC Calculations.
- R7: Economic solutions and energy market.
- R8: Prominent challenges, current status, and future opportunities.

***Cross (×) sign indicates 'no', Tick (✓) sign indicates 'yes'**

where V_1, V_2, and V_0 are the positive, negative, and zero sequence voltages, respectively. V_a, V_b, and V_C are the line-line voltages, $a = 1\angle 120°$.

Further, the authors in [60] proposed a distribution factor (D_f) to specify the voltage unbalance due to governed variables such as DERs rating and location, as demonstrated in Eq. (4).

$$D_f = \left| \frac{N_a}{N_{total}} + a\left(\frac{N_b}{N_{total}}\right) + a^2\left(\frac{N_c}{N_{total}}\right) \right| \tag{4}$$

here N_{total}, N_a, N_b, and N_c donate respectively the total number of DERs coupled into all phases, and the number of DERs connected to phases a, b and c.

The authors in [23] found that the HC plunged from 26% to 20% due to the various phase connections of the BESSs which were random in Case (A), connected in the same phase of PV inverters in Case (B), and in Case (C) the load uncertainties were analyzed. To mitigate the voltage unbalance issue, the BESSs were applied by specifying their optimal capacity and locus [61]. Here, the PV HC was raised from 393.9 to 463.6 kW in phase A, phase B (233–578 kW), and phase C (318–495 kW) under load and generation uncertainties.

3) VOLTAGE FLICKER CRITERIA

Voltage flicker (VF) is a phenomenon in which the voltage waveform at the MPS oscillates rapidly and randomly. The most common causes of voltage flicker can be varied as the power electronic-based devices such as PV inverters, low-frequency voltage harmonics, high rate deviation of load sharing at the PCC, voltage mitigation techniques, industrial loads (induction motors with speed soft starter or drivers), varied allocation and capacity of DER stations and EV charging stations or aggregators, and finally the environmental conditions like clouds, wind speed and solar irradiance variations [11], [18]. Relating to various applied standards, voltage flicker measurement indices can be classified into short-term (Pst) and long-term (Plt) flicker indices in addition to the acceptable international constraints depicted in [62]. To mitigate the voltage flicker influences, various control schemas and reactive compensation methods, like FACTS and PV inverters, are discussed during the integration of DERs, ESSs, and EVs with different operation scenarios. In [63], a comprehensive review of voltage flicker mitigation techniques was studied in highly PV-rich LVDSs over a three-level control strategy.

The authors in [64] proposed a three-level control scheme to reduce the voltage fluctuations and flicker by using the various smart functions of both PV inverters and control instruments implemented in PV-rich LVDSs. Under real-time simulation of the modified 119-node 11-kV test distribution system (DS), the proposed strategy appeared superior compared to other strategies and reduced the voltage flicker index by 0.003%. In [65], the voltage rise and long-term voltage flicker were investigated and evaluated during high penetration of the rooftop solar PVs on real LVDS in Louisiana. That concluded 10% of customers could implement 7 kW-PVs under exceeding the 30% of penetration level in which significant PQ issues were observed. Hence, the overview of utilizing PV inverters with the ability to support the voltage quality and prevent the reverse power flow was deliberated for LVDSs in [66]. Owing to the stochastic nature of wind speed, the FACTS devices were applied in the wind energy conversion systems (WECSs) to minimize the voltage flicker and improve the PQ by optimizing the UG current deviations [67]. So, the optimal planning of the LVDSs should consider voltage flicker and other voltage deviation problems as pivotal constraints in the optimization objective function. Hence, the optimal allocation (size and capacity) of ESSs, WTs, and PVs with the contribution of other compensation devices were revealed in planning problem to avoid the voltage flicker in [68] and [69]. Moreover, the voltage deviation issues especially voltage flicker were discussed during the integration of the fast EV charging stations and their effects on the PQ of LVDSs [70]. According to industrial applications especially the electric arc furnace, the static var compensator (SVC) was employed as a voltage flicker mitigation technique [71].

B. AMPACITY AND THERMAL OVERLOADING PROBLEMS

Corresponding to the incremental integration the DERs into MPSs, it is crucial to estimate the current carrying capacity (ampacity) and thermal overloading of cables, CBs, transformers, and other types of equipment, which is not a unique value, but it depends mainly on the DSOs' experiences, rules of thumb, and applied standards. The ampacity and thermal overloading problems of various implemented components in MPSs can be occurred mainly due to the reverse power flow and voltage deviation at off-peak periods within the electrical demands less than the generation. Moreover, the bidirectional power flow among generation buses especially at unbalanced peak loads, and ageing models of various equipment, which make the designed capacity of lines, transformers, cables, and other equipment, will be exceeded causing the overheating and operational failures obstacles [12]. So, their limits should be considered and well specified during the HC optimization to avoid exceeding the capacity limits of various power system components. Thus, the maximum penetrated power estimation equation of DERs (P_{DERs}) in LVDSs as a function of both active (P_{load}) and apparent (S_{load}) powers of loads, was proposed in [72] as follows;

$$P_{DERs} = 2 \times P_{load} + (1 - S_{load}) \tag{5}$$

During the HC evaluation, the limits of ampacity and thermal overloading of various equipment are specified and discussed in several articles. However, these limits are associated with different factors that should be deliberated on such as the influence of EV charging stations, DERs, and ESSs, load variations, equipment capacities, and environmental conditions.

In [73] and [74], the various PQ issues due to the integration of the EVs into the ADNs are discussed in terms of voltage unbalance, VF, harmonics, ampacity, and the thermal overloading of cables, lines and transformers thus affecting their life expectancy because of the fast charging stations.

Therefore, the authors in [75] stated some vital solutions based on the optimal allocation, and scheduling of the EV charging stations in the LVDSs using Bi-level planning algorithms in view of EV uncertainties. To diminish the worst impacts of EV charging stations, the DRP was proposed considering the thermal overloading of transformers [76]. Not only the PIs of PQ were enhanced but also the life expectancy of transformers increased to 20.55 years with 50% penetration of smart EV charging stations without developing or augmenting the existing infrastructure of ADNs, compared to 1.55 years at the worst charging scenario during different seasons of the year.

According to the evaluation of TR under both current and temperature restrictions and ageing considering the DERs, ESSs, and EVs, the dynamic TR feasible region is investigated in cold and warm climates without requiring any load profiles [77]. As a result, an additional capacity higher than 100% of nominal TR was achieved. The authors in [78] used both deterministic and stochastic approaches to quantify the HC associated with the component load ability of transformers and feeder cables with planning strategies. While in [79], the thermal modelling and capacity of transformers were considered as agents in HC optimization functions for energy management of LVDSs using EVs and heat-pumps based on load and temperature predicting.

C. POWER LOSS PROBLEMS

As a result of reverse power flow during the uncontrolled penetration of DERs, power loss problems are occurred, which are mainly depended on the ampacity of cables and their length as depicted in Eq. (6).

$$P_{loss} = \sum_{t=1}^{T} \sum_{l=1}^{L} \left| i_l^t \right|^2 R_l \tag{6}$$

where i_l^t is the current through the specific line (l) in time (t), R_l is the total resistance of the line. Hence the total power loss is calculated over all time (T) and lines (L).

Consequently, it is critical to state the accurate location and capacity of DERs and ESSs in order to overcome the overloading of the cables and connected transforms which lead to solve the power loss problems. Several studies are conducted for optimal network planning of the ADNs using probabilistic analysis in terms of the technical and economic limiting constraints considering cable and transformer capacities [53], [80]. In [7], the imitation of power loss can be solved by installing the DERs near the served feeder, which will lead also to reduce the thermal overloading and increase the life expectancy of equipment, under an accurate balance between the generation capacity and electrical demands especially in off-peak loads. The various PIs related to the line losses were considered in [81] to specify the optimal DGs' location in 4-bus and IEEE 33-bus radial DSs. To deal with the reverse power flow, energy loss and voltage violation, multi-objective optimization techniques were utilized to allocate the PVs with a suitable capacity [82]. The study concluded that the voltage violation occurred beyond 30% of PVs penetration level, however, the various negative impacts of high-level penetration were overcome by installing high DERs' capacities. Other optimization algorithms are applied for the optimal placement of FACTS [83], DERs [84], and RESs with risk evaluation [85] to reduce the overall power loss in MPSs. Another approach based on load shifting provided the DRP performed optimal planning and allocation of DERs for minimum power losses [86]. In [87], recent methods for diminishing power losses and evaluation are argued and established on the relationship between individual prosumers and energy communities.

D. POWER QUALITY ISSUES

In this subsection, the crucial PQ factors to measure the performance of the MPSs between the UG and prosumers may have occurred for numerous reasons particularly harmonics and frequency unbalance.

1) HARMONICS

The over-penetration of various new DERs, EVs, and ESSs necessitates high switching frequencies power electronic converters that produce harmonics which deteriorate the PQ of ADNs [7], [40], [60], [88]. Also, it is found that the excessive voltage disturbances due to nonlinear loads, magnetic core of transformers, fast EV charging stations, high voltage DC transmission stations, electrical motors, and others, cause harmonics which lead to shorten the lifetime of the power system components, negative impacts on other PIS, and maloperation of protection devices. So, it is essential to keep the total harmonic distortion (THD) within acceptable limits to sustain good PQ in ADNs. The percentage of the THD of voltage or current components ($THD_x\%$) per bus can be calculated as;

$$THD_x\% = \frac{\sqrt{\sum_{i=2}^{H} \left(X_{i,h}\right)^2}}{X_{i,1}} * 100 \tag{7}$$

where $X_{i,h}$gives the voltage or current components according to the harmonic h at the node i; $X_{i,1}$ is the fundamental voltage or current components at the node i. H highlights the maximum harmonic order applied for calculations.

From the literature, the HC was calculated by considering the acceptable limits of harmonic distortions for PV-rich distribution systems in non-sinusoidal environments in addition to analyzing other PIs of the PQ study [89], [90]. The results showed that the THD was increased relative to the non-linear loads' existence, which affected the HC level. Therefore harmonic mitigation techniques were proposed such as passive filters to reduce the THD [90]. Hence, new harmonics assessment methods were suggested for achieving optimal power flow and scheduling the both various DERs and ESSs' location and capacities with uncertainties besides investigating the effective placement of harmonic control equipment, and FACTS in [91], [92], and [93]. The negative influences of EV charging stations were discussed based on the harmonic distortion concerns in addition to proposing new evaluation methods using combined deterministic and stochastic methods to improve the HC of EVs in [94], [95], and [96]. With the presence of robust optimization algorithms and data-driven methods, the HC improvement methods were studied regarding the PQ issues especially minimizing the THD in [97] and [98].

2) FREQUENCY DEVIATION

Another challenge of over-penetration of the DERs on the ADNs based on the PQ concerns is the frequency deviation caused by decreased overall system inertia, unbalance between generated and consumed powers, and sudden load variations [53], [99]. The frequency disturbance may cause damage to generators, system instability, and blackouts. Thus, the inertia of synchronous generators (SGs) in the rotating parts controls the required time response to energy variations until the governor's response rotating parts to maintain the balance power flow [100]. However, the speed variation of the SGs leads to frequency deviations within the maximum acceptable ratio (1%), otherwise, loss of synchronism occurs. Owing to the increased replacement of SGs by non-SGs, the power system inertia is decreased in MPSs [101]. So, it is required to apply accurate frequency control methods regarding the stochastic characteristics of DERs and load variations in the ADNs planning stage. Hence, some frequency control techniques are investigated such as automatic generation control (AGC) regulators, and local frequency control (LFC) using optimization and data-driven methods [54], [99], [102], [103], [104]. Moreover, new virtual inertia compensation methods are used to improve the frequency stability in low-inertia ADNs, as discussed in [105], [106], [107], and [108].

E. PROTECTION CONCERNS

The excessive DERs penetration higher than the energy consumption demands causes reverse power flow, varied magnitudes of fault currents, and other protection problems [109]. This may increase the maloperation risk of protection systems and other connected equipment, in turn, decreasing the power system reliability. Current protection schemes are designed to operate in unidirectional power flow conditions. However during bidirectional power flow, several obstacles have appeared for instance; overvoltage, misoperation of protective relays, CBs, re-closers, fuses, blackouts, and voltage regulators [7]. So, advanced protection coordination strategies are applied based on centralized control methods and communication solutions.

F. OTHER PERFORMANCE INDICES

1) ENERGY CURTAILMENT

During the overvoltage condition, the APC strategies are applied to regulate the total generated active power ($Total\ \ generated\ P^{DERs}_{nominal}$) from the various types of DERs in ADNS to match consumption necessities without violating the operational UG limits [109]. APC strategies involve three conditions, as demonstrated in the following equation.

$$Total\ generated\ P^{DERs}_{nominal} = \begin{cases} 0 & \forall\, V_{act.} \geq V_{max} \\ P^{DERs}_{max} \times \dfrac{(V_{max} - V_{act.})}{\left(V_{act.} - V_{ref}\right)} & \forall\, V_{ref} \leq V_{act.} \leq V_{max} \\ P^{DERs}_{max} & \forall\, V_{act.} \leq V_{ref} \end{cases} \tag{8}$$

where P^{DERs}_{max}, $V_{act.}$, V_{max}, V_{ref} are the maximum generated active power from DERs, actual, maximum, and reference operating voltage, respectively.

Although sustaining the normal operation, the output power loss (total amount of curtailed DERs' active power) on the end feeders connected to the DERs increases more than others [110]. So, various droop coefficient schemes should be applied to ensure power loss for all DERs' feeders using smart inverters, local measurements with limited communications, and others.

2) POWER FACTOR

Controlling the reactive power exchanged among feeders, this reflects directly on the power factor (PF) which can be used as an important PI for assessing the HC study besides the voltage, as determined in the following equations:

$$Pf_i = \frac{P_i}{\sqrt{(P_i)^2 + (Q_i)^2}} \tag{9}$$

in which

$$\varphi_i = \angle V_i - \angle I_i \tag{10}$$

$$P_i = V_{irms} I_{irms} \cos(\varphi_i) \tag{11}$$

$$Q_i = V_{irms} I_{irms} \sin(\varphi_i) \tag{12}$$

The phase-locked loop (PLL) block is applied to examine and calculate these variables. Here, φ_i is the phase angle for the same phase i. Then P_i, Q_i, V_{irms}, and I_{irms}, are the active and reactive powers, and both rms values of the phase voltage and current, respectively.

With respect to the optimal placement of PVs, the HC improvement was evaluated under several operation PFs using RPC schemes [111]. The HC increased to 96% during operating with lagging PF than operating with UPF condition. Similarly, the genetic algorithm (GA) was applied to calculate the HC under variable PF operation [112]. The results depicted more HC accommodation in the LVDSs during operating at non-unity PFs and the study can be expanded using various approaches of HC enhancement. In [113], the EV-HC was evaluated in unbalanced LVDSs during peak demands in which the PF was considered in EV demand profiles by using the PF correction methods installed in EV chargers.

3) RISK INDEX

The RI is a tool applied to evaluate and determine the level of risk associated with any predictable deflection or fluctuations of any system variables such as voltage or frequency and their consequences on the power system operation as a result of increased penetration of DERs. The RI for any bus ($RI\ (X_i)$) can be represented in the worst-case of probabilistic load flow for any system variables in the optimization objective function for security concerns [85].

$$RI\ (X_i) = P_i \times A(X_i) \tag{13}$$

where $\mathbb{P}_i$ is the probabilistic limit of the applied system variable at any bus (i) that will exceed the acceptable constraints. $A(X_i)$ is the average deviation of the utilized system variable at a specific bus which can be calculated as;

$$A\ (X_i) = \left|1 - \overline{X}_i\right| \tag{14}$$

In [85], the normal conditions in high-level penetration of DERs were maintained using the optimal allocation of DERs and voltage control methods to evade the risk of over/under voltage. Likewise, the stochastic risk evaluation approach was applied considering the high penetration of DERs, and multi-energy carrier ESSs regarding the economic and technical risks aspects [114], [115], [116].

G. SUMMARY OF LIMITING CONSTRAINTS

The most important PIs used for evaluating the HC are voltage and ampacity, other PIs in turn depend on them. The researchers may use one or more PIs to assess the HC of their studied systems. Thus, it is critical to specify the limits of various PIs in LVDSs for accurate HC evaluation under several vital aspects for instance; applied global standards, system parameters, equipment and configuration, capacity and position of DERs, EVs and ESSs, load variations, and environmental concerns. Table 3 summarizes the most important limiting constraints and recommendations of applied PIs for HC assessment in the LVDSs in which the data collected from [11] and [18].

Regarding to the limiting constraints in HC assessment for various countries given in Table 3, most of them recommended to use ±5% of Vn for voltage violation limits, both cable ampacity and transformer rating are from 100% to 150% of nominal rating, and voltage unbalance as 1-3% of Vn. The authors recommend to use the following values of limiting constraints to evaluate the HC based on increasingly applying in various articles: voltage limits ±10% of Vn; both cable ampacity and transformer rating 125% of nominal rating; voltage unbalance 3% of Vn; THD(v,i) ∼5%; PF range : 0.95; and frequency range: ±0.3% of nominal value. The authors recommend working on developing a unified HC index that can assess conflicting aspects including techno-economic and environmental factors. Based on the authors' background, there is no efforts directed to this research.

V. HC ESTIMATION APPROACHES

From the above discussion, it is observed that the HC estimation is a challenging trajectory to implement as directly depends on the variation amount of DERs, connected feeder, and various PIs for instance "voltage and frequency variations, thermal overload of both cable and transformer, PQ and protection problems" [40]. For the general presentation of HC calculations, several concepts are applied for various approaches in many works by Eqs. (15-18). By assuming that total additional DERs can be installed into specific buses of feeders (N) for given LVDSs with respect to consumer demand without violation of any limiting constraints, the total HC of the network (HC_N) is formulated as;

$$HC_N = \sum\nolimits_{b=1}^{N} P_b^{DERs} s.t., \left|P_N^{DERs}\right| \leq \left|P_N^{load}\right| \tag{15}$$

where P_b^{DERs} are generated power of DERs connected to the specific bus (b), N is the total number of system busses. P_N^{DERs} and P_N^{load} define the total generated power of DERs and total consumers' demand, respectively, for all total connected buses. Hence, the penetration level percentage of DERs $\lambda(\%)$ can be determined as follows;

$$\lambda(\%) = \frac{\sum_{b=1}^{N} P_{DERs,b}^{max}}{\max\left(\sum_{t=1}^{T} P_{load,t}\right)} \times 100 \tag{16}$$

where $P_{DER,b}^{max}$ is the maximum power of installed DERs at the specific bus, $P_{load,t}$ denotes the electrical load with respect to the total time (T).

The HC can be determined as a relationship of transformer capacity (S_t^{rated}) or maximum consumers demand ($\max(P_N^{load})$). By assuming that all used transforms are in the same size and high ratings with limited considerable constraints, the transformer HC can be calculated by;

$$HC_t = \frac{HC_N}{\sum_{t=1}^{N} S_t^{rated}} \tag{17}$$

While the HC relative to maximum demands (HC_{ml}) is defined as;

$$HC_{ml} = \frac{HC_N}{\max\left(P_N^{load}\right)} \tag{18}$$

Moreover, the generic detailed steps for HC estimation approaches are summarized as follows in Table 4.

In this section, the various HC calculation approaches are deliberated which can be depicted into three main groups namely, conventional, modified, and data-driven approaches, as shown in Fig. 5, which captures most of the HC assessment approaches corresponding to various recent publications. Further, the comparative study and recommendations are involved with various approaches' features.

A. DETERMINISTIC APPROACHES

The deterministic approaches depend mainly on the prior-knowledge data of both technical and economic parameters of the ADNs in addition to DERs generation and energy consumption, which can be fixed or variable during the calculation period [53]. Although their calculation simplicity with low computational time, these methods do not reflect the realistic nature of uncertain variables which is considered

TABLE 3. Limiting constraints of applied PIs for HC assessment in the LVDSs.

Ref.	Country	Most-utilized PIs of HC assessment						Applied global standard	Limiting constraints	General standard recommendations of undefined PIs
		PI1	PI2	PI3	PI4	PI5	PI6			
[25], [61], [117]	Australia	✓			✓			Australian	PI1:-6/+10% of Vn or -5/+5 or +6% of Vn; PI4: 1-2% of Vn	PI1: ±5% or ±10% of Vn; PI2, PI3 : 100%–190% and 85%–150% of nominal rating; PI4:1-3% of Vn; PI5:short-term <1 (1min.), long-term <0.5 (3 days to a week); PI6:THD(v,i) ~1-8%; PF range : 0.95–1.00; Frequency range : ±3% or ±0.3% of nominal value
[22]	Brazil	✓		✓	✓			-	PI1: -8/+5% of Vn; PI3:187.5% of TR; PI4: 3% of Vn	
[118]	Canada	✓						CSA	PI1:±6% of Vn	
[119]	China/ Taiwan	✓	✓	✓				-	PI1: ±5% of Vn; PI2: 100% of CR; PI3:100% of TR	
[120]	Cyprus	✓						EN-50160	PI1: ±10% of Vn	
[59], [121]	Denmark	✓			✓			EN-50160	PI1:+5% of Vn; PI4:2% of Vn	
[122]	Egypt	✓				✓	✓	-	PI1: ±10% of Vn; PI5:short-term <1 (1min.), long-term <0.8 (3 days to a week); PI6: <5% THD; PF>0.9; Frequency:-3%/+2% of 50Hz	
[123]	European	✓						EN-50160	PI1:±10% of Vn	
[23], [24]	Finland		✓	✓				EN-50160	PI1: ±10% of Vn; PI2: 100% of CR; PI3:100% of TR	
[124], [125]	Germany	✓	✓	✓		✓		VDE-AR-N 4105	PI1: +3% of Vn; PI2: 150% of CR; PI3:150% of TR; PI5: (0.5-1)	
[126]	Indonesia	✓						-	PI1:+5% of Vn	
[127]	Italy	✓				✓		ANSI C84.1	PI1:-4/+10% of Vn; PI5:6% of rated value	
[128]	Japan	✓						-	PI1:+5% of Vn	
[129]	Mauritius						✓	IEEE 519-2014	PI6: 1.9% to 6.1%	
[130]	Philippines	✓						-	PI1:+5% of Vn	
[131]	Qatar	✓	✓	✓				-	PI1: ±6% of Vn; PI2: 100% of CR; PI3:100% of TR	
[20]	South Africa	✓						EN-50160	PI1: ±10% of Vn	
[132]	Sri Lanka	✓			✓			-	PI1:+6% of Vn; PI4:1% of Vn	
[133]	Sweden	✓						-	PI1: ±5% of Vn	
[28], [134]	Switzerland	✓	✓	✓				-	PI1:+3% of Vn; PI2: 85% of CR; PI3:100% of TR	
[135]	UK	✓			✓		✓	BS EN-50160	PI1:-15/+10% of Vn; PI4: 1.3% of Vn; PI6: 5% THDv	
[65], [136], [137]	USA	✓	✓		✓			ANSI C84.1	PI1:±5% of Vn; PI2:105% of CR; PI5: (0.03)	

*PI1:voltage limits; PI2:cable ampacity; PI3:transformer overloading; PI4: voltage unbalance; PI5: flicker; PI6: harmonics; TR: transformer rating; CR: cable rating;

a worst-case scenario for validating the system robustness and reliability [6]. These methods use forward, backward, or forward-backward procedures to estimate the HC due to DER deployment [9]. Their strategies depend on perturbing the DERs' capacity in steps, calculating the HC until one or more limiting constraints are violated. These approaches are classified according to the type of provided load consumption and generation dataset as the constant generation method and the time series method in which the input data of system parameters are fixed [12].

In the constant generation method, the load, and DERs generation profiles are assumed constant in their maximum rate which don't reflect their stochastic nature and variety during calculating the HC to make a sensitivity analysis of DERs' deployment in the ADNs. On the other hand, the time series method takes into account the variety of DERs generation and load profiles over calculation time which is totally based on the provided historical dataset without considering the current uncertainties of DERs, EVs, and ESSs. It may calculate the HC using a limited number of scenarios to avoid the large amount of data consequences on the computational time that influence the calculation accuracy. Several articles used the deterministic approaches to estimate the approximate HC for MPSs as summarized in Table 5.

B. STOCHASTIC APPROACHES

As an opposite of deterministic approaches which don't consider any uncertainties of generation units and load demand profiles besides the variation of capacity and location of utilized DERs, stochastic approaches are developed to overcome these obstacles and reflect the realistic HC estimation [40]. The different uncertainties can be classified into prosumer or feeder, location, and power injection uncertainties as deliberated in section III-C. The strategy is reliant on predefined

TABLE 4. General procedures of HC estimation approaches.

Step 1 **Input**: {selected performance index, limit of performance index, amount of DERs};
Step 2 **Output**: {enhanced HC};
Step 3 **Initialize:** inputs values;
Step 4 **Calculate** the performance index as a function of DERs' amount;
Step 5 **Execute** the model with load flow algorithm;
Step 6the **If** performance index result is ≤ its limit
  Increase the amount of DERs gradually; and **Return** to Step 5;
Step 7 **ElseIf** performance index result > its limit
  If {not applying HC enhancement techniques}
   Uncontrolled HC= the amount of DERs from Step 6;
   Go to Step 10;
  Else Apply suitable HC enhancement techniques;
  Endif;
 Endif;
Step 8 **Execute** the model with load flow algorithm considering applied HC enhancement technique;
Step 9 **If** performance index result ≤ its limit
  Increase the amount of DERs gradually; and **Return** to Step 8;
 Else Controlled HC= the amount of DERs from Step 9;
 Endif;
Step 10 **End for all;**

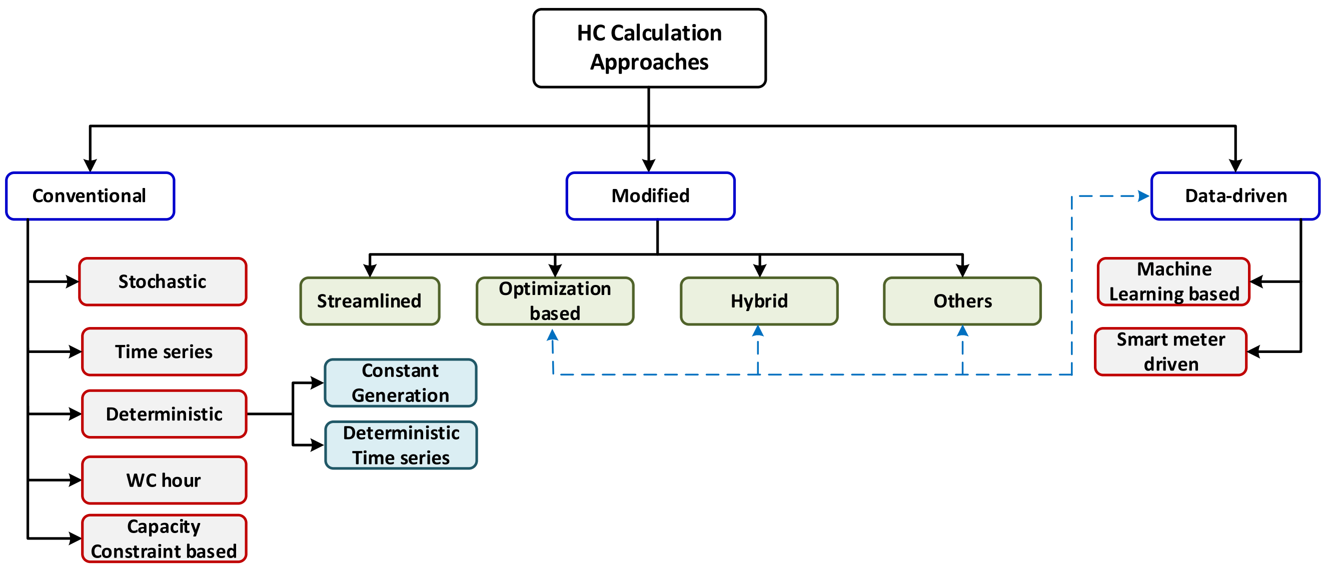

FIGURE 5. HC calculation approaches.

PIs' constraints, a large range of random scenarios and the uncertainties of input variables. Which are depicted by probability distribution functions (PDFs) or probability mass functions (PMFs) that are created from collected historical data [57]. From that the baseline power flow analysis is performed iteratively by gradually varying the capacity and the location of DERs until exceeding the PIs' violation is observed. The stochastic algorithms are employed numerical and analytical strategies as discussed in [56]. In numerical approaches, the MC simulation algorithms such as sequential and non-sequential MC are applied which are elaborated adequately in [138]. The analytical strategies attaint the PDF or PMF of the output variables as a relationship of the PDF or PMF of their input variables by linearization-based and approximation-based approaches [10]. The probabilistic approaches also are capable of predicting and sensitivity studies of real-life scenarios [139]. However, these methods might not give the optimal solution because of misconnection among network variables, inaccurate historical data, and an increased number of uncertainties and applied scenarios. That will lead to an increase in the simulation complexity, computational time, and memory usage. A summary of recent articles that applied the stochastic approaches is represented in Table 6.

C. WORST-CASE (WC) HOUR APPROACH

By considering specific hours over the whole day, the deterministic or stochastic approaches can be used to calculate the worst-case (WC) hour scenario to investigate the PQ and reliability of the MPS, and predict their performance under sudden disturbances for avoiding power outage [11], [140], [141]. For the same purposes, the WC approach is considered as robust approach in optimization-based algorithms not only for HC estimation but also aiding on power system planning and operational decision-making. The WC hour approach studies the specific period of both minimum and maximum demand scenarios which is sufficient for HC calculation with less computational burden. However, the results are associated with the availability and accuracy of the applied dataset which can lead to overestimation and miscalculation of HC in ADNs. The MC method was used to optimize the DERs' placement and size to sustain reliable operation with acceptable voltage deviation limits during the WC hours [142]. Similarly in [24], the MC method was applied to analysis the HC of the Finnish LVDS under several limiting constraints by considering the WC hour strategy.

D. TIME SERIES APPROACHES

Time series approaches are considered as an upgrade of deterministic approaches that give realistic HC value based on long time-scale and high-resolution historical data or actual measurements of the ADNs. Instead of using fixed data of input variables in the deterministic approaches, the time series approaches to deal with the changeable dataset of various input variables with their uncertainties such as generation and load curve profiles dependent on the time-varying [9]. The strategy is dependent on varying the technical characteristics of DERs at each time until reaching the maximum allowable DERs for the ADNs in which 5- 10 seconds time resolution of applied data is recommended. For a short time span (24 hrs.), these approaches can generate required data profiles for HC calculations however in a long time span, as autoregressive moving average (ARMA) and autoregressive integrated moving average (ARIMA) algorithms can provide alternatively the time series data [57].

The most popular applied tools are the quasi-static time series (QSTS) simulation [157] and dynamic HC analysis [158]. The QSTS simulation solves a data series of sequential steady-state power flows in each time step based on the previous time steps which require high-resolution data and computational burden. On the other hand, dynamic analysis captures time-dependence data for the long-term period to verify the full grid impacts and sensitivity and calculate the annual energy losses. Thus, the dynamic HC can be 60%–200% higher than the HC calculated with statics methods. The time series approaches give a more accurate HC value if both high-resolution measurement data and a high computational burden are used. A summary of recent articles that applied the time-series approaches is represented in Table 7.

E. CAPACITY CONSTRAINT-BASED

For initial HC estimation, the capacity constraint-based (CCB) approach is implemented which depends mainly on the historical data collected from the various measurement meters [10]. The CCB approach studies the acceptable capacity constraints of DERs, EVs, and ESSs that are integrated into the ADNs without endangering the PQ or exceeding the limiting constraints of PIs. This approach investigates the imported data of ADNs' parameters and their operational limiting constraints, then the optimization algorithms calculate the HC by incrementally increasing the capacity of DERs or other technologies until reaching the accurate HC value. Hence, the uncertainties of DERs are not considered in the power flow simulation. Although the forecasted data of generation or load profiles can be considered, its accuracy is highly contingent on the applied data collected from smart meters with relative reading errors. As a result, this approach may not be reflected in the real operation of ADNs because of the limited applied scenario. This method is applied to estimate the maximum DERs' capacities of ADNs using a two-stage optimization algorithm based on "unbalanced three-phase power flow modelling and active network management (ANM) techniques" [159]. The authors in [160], proposed a new strategy based on the estimation of the violation of the PIs initially then decreasing the DERs' capacities selectivity and gradually until the sustain the optimal operation conditions. In [161], the maximum HC was evaluated using an optimization algorithm based on the capacity constraints of the ADNs. While in [162], the capacities of MESs were estimated to supply the electrical, cooling, and heating demands coupled into microgrids that connected to remote ADNs.

F. STREAMLINED APPROACH

The streamlined approach is used to estimate the HC and perform power flow and short-circuit analyses in the ADNs without simulating a large number of scenarios like stochastic approaches. Moreover, giving an accurate overview of daily variations for the electrical characteristics and the load profile and giving the proper location and capacity of the integrated DERs similar to time series approaches [56]. Two types of streamlined approaches are employed such as the Streamlined

Integrated Capacity Analysis (ICA) method and another approach developed by EPRI [10]. The strategy of streamlined approaches is based on continuously simulating a pre-defined set of equations and algorithms to evaluate the PIs at each bus after a baseline power flow analysis is performed to attain the initial circumstances of ADNs [57]. Corresponding to their features, simple data are required considering the uncertainties of DERs and compact computational burden. Also, three values of HC "(realistic, optimistic and conser-

TABLE 5. Selective studies of deterministic HC estimation methods.

Ref.	Year	Country or Network type	Controlled PI	HC technology	HC enhancement		Study Objectives
					Yes	NO	
[143]	2014	69-and 33-bus LVDSs	PI1,PI3	PV		✓	Proposed analytical expressing for calculating the optimal size and location of PV systems as a function of voltage deviation and power loss indices also based on time-varying load models and probabilistic PV generation.
[144]	2016	Several benchmarks	PI1,PI4	PV		✓	Estimated the maximum PV generation that could be integrated into the ADNs.
[145]	2017	GridLAB-D modelling tool	PI1,PI2,PI3,PI6	DG capacity		✓	Calculated the acceptable DG capacity considering phase mutual inductance and line losses.
[146]	2017	Sweden and Germany	PI1, PI5,PI7	Single-phase PV, EV charging stations	✓		Studied the influence on several networks due to integrating the single-phase PV systems and EV charging stations and how to reduce the bad consequences which lead to voltage unbalance
[147]	2017	Sweden (Herrljunga)	PI1,PI2	PV	✓		Studied yearly PV penetration with their adverse impacts such as voltage deviation and thermal overloading. Also, proposing a new method to overcome these influences using a power cutoff technique, and ESSs with applicable smart inverters.
[126]	2018	Indonesia (Yogyakarta)	PI1,PI2, PI4	PV		✓	Analysis of the HC of LV and MV networks in Kentungan.
[148]	2018	Campus grid	PI1, PI6 (harmonics)	PV		✓	Consider the THD limit on HC calculation.
[149]	2019	IEEE 13-bus LVDS	PI3, PI6 (harmonics)	PV		✓	
[150]	2020	IEEE 33-bus LVDS	PI1,PI2	EV		✓	Estimated the maximum EV HC for DSs under some considerations.
[151]	2021	Several benchmarks	PI2	EV		✓	
[152]	2021	IEEE 37 bus and IEEE 123 bus LVDSs	PI1,PI7	PV		✓	Employing an analytical approach based on voltage sensitivity analysis for random multiple allocations and stochastic constraints of PV systems without high computational burden.
[153]	2021	33-bus LVDS with 6-node heat network	PI1,PI2	PV		✓	The maximum PV HC was determined using the linearization method based on the Big-M method for the complex non-linear model of MESs including electrical and heat EHs.
[154]	2022	IEEE 33-bus LVDS	PI1,PI2	Multi-type DERs		✓	Calculating the optimal locations of single or multi-type DERs based on provided parameters mathematically then the optimal power flow (OPF) applied to estimate the optimal capacities of DERS related to previous selective optimal locations.
[155]	2022	IEEE 8-bus and 123-bus radial LVDSs	PI1, PI2,PI6	PV		✓	A constructive model with three rules to overcome the analytical HC estimation methods based on geometrical understanding, historical dataset, and realistic constraints.
[156]	2023	IEEE-33-bus, IEEE-69-bus radial LVDSs	PI1,PI3	DG, EV	✓		Involved three stages to accommodate the optimal size and location of EVs, and DGs into ADNs without violating technical and economic constraints. In the first stage, EVs were located at the best bus then using optimization algorithms for planning the DGs before regulating charging and discharging ratios analytically to minimize the power losses.

*PI1:voltage limits;; PI2:thermal overloading; PI3: Power losses; PI4:reverce power flow; PI5: protection limits; PI6: power quality; PI7: Reliability and sensitivity

vative)'' can be given with acceptable accuracy besides their capability to forecast the DERs expansions, load profiles, and network reconfiguration, to analysis the HC assessment methods using the collected data from smart meter and other monitoring devices [12]. In [163], the factors and challenges of various HC calculation methods are discussed especially streamlined approaches. The location of PV systems was optimally optimized on individual feeders without violating the technical constraints [164].

G. OPTIMIZATION-BASED APPROACH

To handle the computational challenges and complexity associated with the pervious approaches, the optimization-based approaches can deal with the power flow simulation which can be deterministic, stochastic, or data-driven frameworks to obtain the optimal HC value [57]. In these approaches, the input variables data with their uncertainties and constraints are defined as an optimization problem before running the power flow simulation to maximize the power injection of the DERs penetration into the ADNS without violating the technical and economic constraints. There are various classifications based on applied strategy, variables domain, and many objective functions as depicted in Fig. 6. Moreover, the optimization problem can be formulated to minimize the different types of cost, emission, and power loss, and to maximize power injection, reliability, life span, and profits [193]. Hence, single or multi-objective algorithms can be applied for any variables domains or strategies to solve the optimization problem involving various constraints. Each optimization algorithm has its advantages and drawbacks,

TABLE 6. Selective studies of Stochastic HC estimation methods.

Ref.	Year	Country or Network type	Method	HC uncertainties	Controlled PI	HC technology	Considering HC enhancement: Yes	Considering HC enhancement: NO	Study Objectives
[165]	2019	LV and MV Feeders	MC	DER capacity and location, load deviation, power injection	PI1→PI7	PV	✓		R1, R2
[166]	2019	33 and 135 bus systems	Power flow simulation		PI1,PI7	WT, PV	✓		
[167]	2020	IEEE 33 bus system	MC		PI1,PI6			✓	
[168]	2021	IEEE 69-bus and real systems	Fast-specialized point estimate method compared to MC and Cumulant approaches	DG capacity and location, load deviation	PI1,PI3,PI4	DG		✓	
[169]	2021	-	MC	(5) EV uncertainties	PI1,PI7	EV		✓	
[170]	2022	IEEE 37 and IEEE 123 bus systems		PV outputs and load demand		PV		✓	• R1, R2 • analysis of spatiotemporal probabilistic voltage sensitivity
[171]	2022	21-bus and 33-bus DC microgrids		(5) EV uncertainties		DG, EV		✓	R1, R2
[172], [173]	2022	LVDS in Northern Sweden with 83 customers		aleatory and epistemic uncertainties at the planning level	PI1,PI2	PV		✓	
[174]	2022	-	General polynomial chaos	(9) planning level and operational uncertainties		PV		✓	
[175]	2022	Network of Armaç˜ao de Búzios	MC	PV constraints, load deviation, power injection		PV		✓	• R1, R2 • Proposed bass diffusion model used for each consumer
[176]	2022	Brazilian LV network		EV and consumer load profiles; PV constraints	PI1, PI2,PI3	PV, EV		✓	R1, R2
[177]	2022	LV and MV Feeders		DG capacity and location, load deviation	PI1,PI2	DG		✓	
[178]	2022	128 real LV feeders in the U.K	Mixed-integer linear programming (MILP), and MC	PV constraints, load deviation, power injection, BESSs, cost	PI6, PI7, cost	PV, BESSs		✓	• R1, R2 • Scheduling the BESSs • Similar to [23]
[179]	2023	IEEE 33-radial bus system	MILP	DER capacity and location, load deviation, power injection	PI1,PI4,	WT, PV		✓	• R1, R2 • New PI developed related to the load deviations

*PI1:voltage limits;; PI2:thermal overloading; PI3: Power losses; PI4:reverce power flow; PI5: protection limits; PI6: power quality; PI7: Reliability and sensitivity;

R1: Calculating the maximum HC of integrated DERs.

R2: Assessment of the PIs of the ADNs.

and the application mainly depends on the user's judgment. Although their ability to overcome the shortcomings of other approaches, they require several iterations to find the optimal solution which needs long computational time and memory, especially in complex power systems with a large number of scenarios. Which can get rid of using linear programming algorithms. A summary of recent articles that applied the optimization-based approaches is represented in Table 8.

H. HYBRID APPROACHES

Hybrid approaches combine the various advantages of conventional approaches and reduce their complexity or long computational simulation time [40]. Other uncertainties of DERs and various limiting constraints can be investigated for a large number of scenarios and feeders. Moreover, these approaches can give a unique value of HC instead of the serval distribution values. Hence, several studies have applied the hybrid approaches for specific objectives in [21], [209], [210], [211], [212], and [213]. To deal with the high computational simulation time in large scenarios number, a multi-parametric programming tool was implemented to accelerate the power flow simulation (10 times) by analyzing the uncertainties and evaluating their impacts [209]. Another algorithm called vine copula was implemented to generate

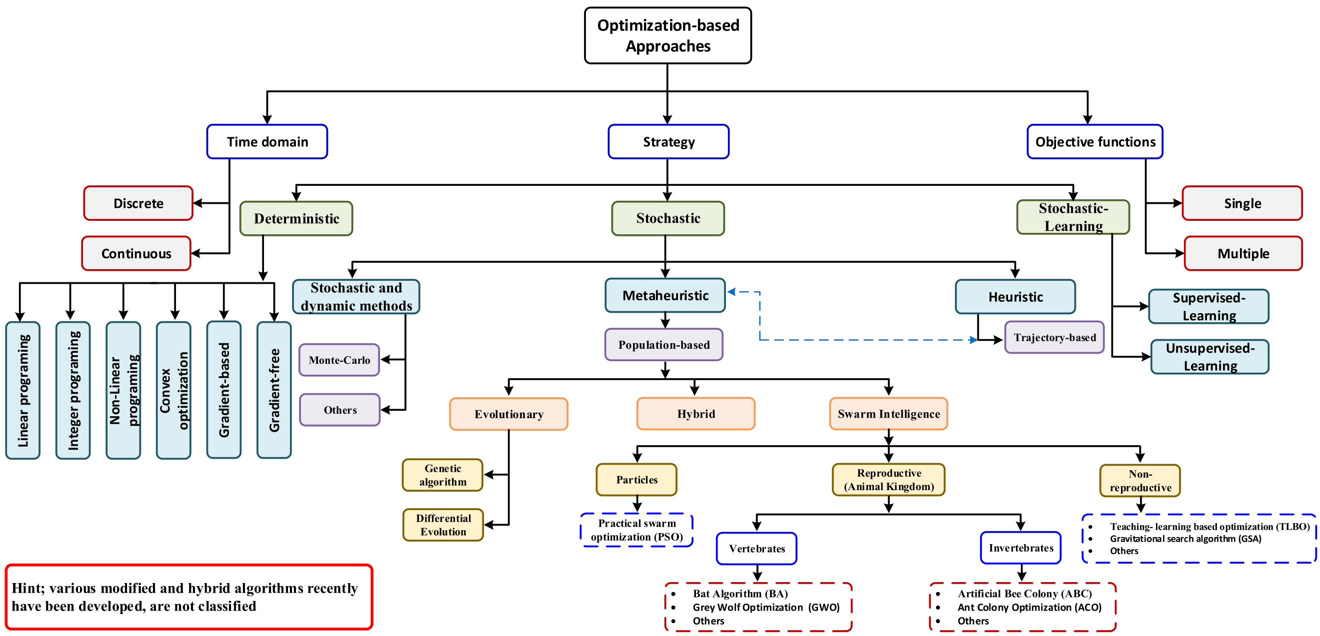

FIGURE 6. Classification of optimization-based approaches [191], [192], [193].

TABLE 7. Selective studies of time series HC estimation methods.

Ref.	Year	Country or Network type	Simulation type	Time step	Controlled PI	HC technology	Considering HC enhancement		Study Objectives
							Yes	NO	
[180]	2017	IEEE 13-bus test system	Fast QSTS	1-second	PI1,PI7	PV		✓	Modelling the controller devices.
[181]	2018	IEEE-123 bus test system		1-min				✓	• R1, R2 • Analysis of the RPC parameters
[182]	2019	Real distribution feeder with 2969 buses (5469 nodes)		1-second				✓	
[183]	2019	Campus data	dynamic	10-min	PI1,PI5,PI6	PV		✓	R1, R2
[157]	2019	Feeder model with 3500 nodes	QSTS	5-min	PI1,PI2,PI6	PV	✓		
[158]	2020	California, feeder model with 943 nodes	Static and dynamic	depends	PI1, PI2,PI3,PI6		✓		
[184]	2020	131 buses UK network	Power flow simulation	10-min	PI1, PI6	PV, BESS	✓		
[185]	2021	DUTH, located in Greece	QSTS	15-min		PV, WT		✓	
[186]	2021	IEEE 123-bus and 33-bus radial DSs	MC and QSTS	1-hr	PI1,PI7	PV, BESS	✓		• R1, R2 • Analysis of the reactive power control parameters
[187]	2022	IEEE 34-bus DS	QSTS	15 min	PI1,PI7	PV, EV	✓		• R1, R2 • Analysis of the depreciation of OLTC lifetime
[188]	2023	EPRI Ckt5 test model	Power flow simulation		PI1,PI5,PI6,PI7	PV		✓	• R1, R2 • Analysis of the RPC parameters
[189]	2023	three Finnish DSs	dynamic	1-hr	PI1,PI2,PI3,PI7	PV	✓		• R1, R2 • Analysis of the economical HC improvement method based on PV curtailment • Similar to [190]

*PI1:voltage limits;; PI2:thermal overloading; PI3: Power losses; PI4:reverce power flow; PI5: protection limits; PI6: power quality; PI7: Reliability and sensitivity;
R1: Calculating the maximum HC of integrated DERs.
R2: Assessment of the PIs of the ADNs.

correlated scenarios before the allocation of the WTs and calculating the HC [212]. A hybrid methodology is used to estimate the HC based on time series methods [210]. To overcome the availability of historical and measurement data, the α-Cut-based strategy was proposed without requiring the PDFs of input variables [21]. Hence, a two-stage optimization algorithm was proposed with the support of both stochastic and time series methods for ANM of the ADNs [211]. In the first stage, a heuristic optimization algorithm calculated the optimal PV base capacity to maximize the HC sum. While the second stage was employed to analyze prior knowledge input variables with their uncertainties obtained from MC simulation, and the generation and load curves using time series methods. This study proposed a two-stage multi-time scale energy management strategy to minimize the operation cost, and regulate the power balance between local generations and peak load for microgrids using both stochastic two-layer framework and online time series approaches [213].

I. DATA-DRIVEN APPROACHES

To fulfil the obligations of the ADNs and overcome the drawbacks of the previous approaches (model-based approaches), the applications of AI algorithms are extensively applied in MPSs [214]. Hence, the data-driven approaches are utilized to process the historical dataset or measured data from smart meters, to develop models for real-time estimation and forecasting of the HC of the ADNs with reliable operation [10]. The data of input variables can be systems parameters and generations of DERs and load profiles with their uncertainties. These approaches are convenient for real-time monitoring of all system characteristics during the high penetration of DERs, ESSs, and EV charging systems [215]. Based on the input variables, the data-driven methods can be classified into smart-meter-driven and ML methods, as shown in Fig. 7. Furthermore, data-driven approaches can be combined with previous approaches to increase their reliability for estimating and predicting the HC of ADNs.

1) SMART-METER DRIVEN METHODS

In these approaches, the collected data from the smart meters through the communication systems are analyzed in terms of the energy consumption, demand response, and optimization of grid reliability, stability, and security for real-time determining and predicting the HC of the ADNs [216], [217]. The effectiveness of these approaches is mainly associated with the accuracy of measurement devices, communication infrastructure, and time intervals of collected data.

2) ML METHODS

The ML methods can be mainly classified into DL, supervised, semi-supervised, unsupervised, and hybrid methods, each of them has its own merits and demerits for applying to specific models. In [218], ML methods are discussed as robust tools for predicting both generation and load profiles, scheduling the flexibility services of the ADNs, and monitoring real-time operation. While the powerful capability of DL methods for frequency control in the ADNs, based on data analysis, prediction, and classification, is elaborated in [54]. Moreover, the classification of ML methods applied to calculate the HC of LVDSs is depicted and compared to other methods in [51]. A summary of recent articles that applied the data-driven approaches is represented in Table 9.

J. OTHER APPROACHES

To deal with the slight shortcomings of previously explained approaches, other robust strategies are implemented which each has its own procedures and power flow analysis such as iterative and Hybrid-DRIVE approaches.

1) ITERATIVE ICA APPROACH

Unlike the streamlined approach, the iterative ICA approach is considered an effective planning tool to evaluate the PIs of the ADNs without using a detailed calculation-based model [163]. It can optimally allocate the DER at a single location at a time and its capacity is increased gradually until perturbing the limiting constraints (thermal and voltage limits). Furthermore, it can perform protection analysis at the attained HC level without delaying the response of the protection devices during fault conditions. Although it's powerful planning criteria within various platforms and performs time-based HC analysis, it still suffers from a large computational burden, especially at ADNs with large numbers of feeders, compact accuracy in large LVDSs, and limited scenario analysis competency.

2) HYBRID-DRIVE APPROACH

In [163], the EPRI has developed the distribution resource integration and value estimation (DRIVE) approach for HC calculation to overcome the computation burden of previous approaches. This approach provides an accurate HC evaluation depending on stochastic analysis with similarity in concept to streamlined and iterative approaches. It creates several power flow scenarios of the feeder response and then calculates the HC-like streamlined approach. In addition, it can be used for analyzing the protection aspects and sensitivity of ADNs in the same manner as the iterative ICA approach [56]. The strategy involves two stages, and their accessible data are attained from the planning and power flow analysis considering the feeder's operation limits initially. Then the various DERs' scenarios are simulated for HC assessment. The least computational time is obtained compared to other approaches, however single-feeder analysis only can be performed at time.

K. APPROACHES' COMPARISON, AND DISCUSSIONS

For accurate selecting decisions of the HC estimation methods in LVDSs, many impact factors should be considered such as various assessed PIs, used dataset, network generation capacity, energy demands and policies, number of uncertainties, DERs' capacity and location, and system configuration and complexity. Relative to the conventional approaches which mainly depend on the model parameters, both deterministic, CCB and WC hour approaches give an overestimated value of HC without considering the

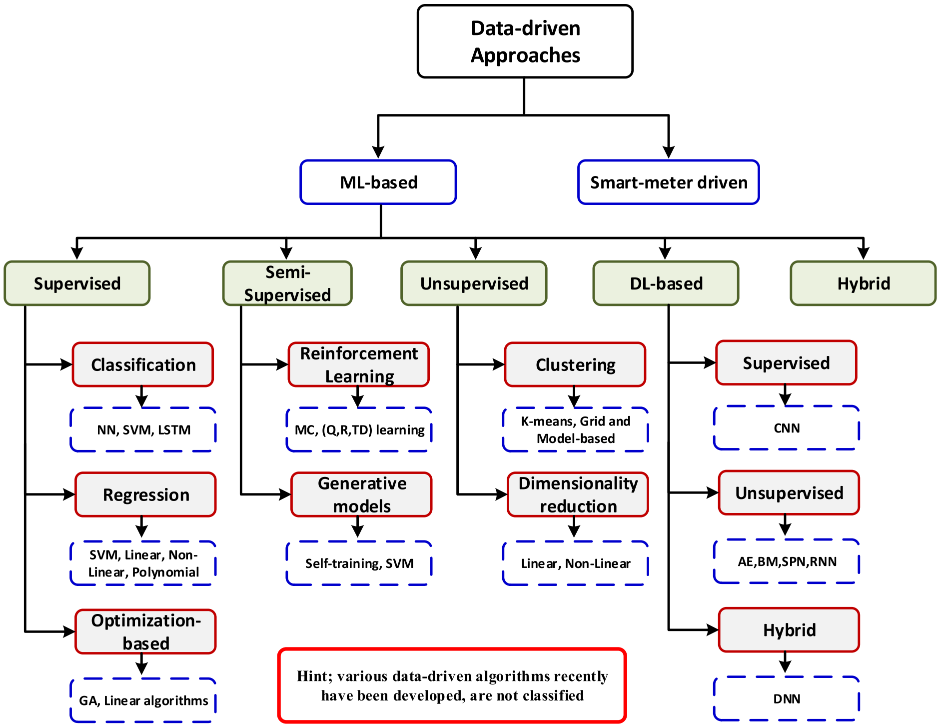

FIGURE 7. Classification of data-driven approaches [10], [54], [218].

uncertainties of input variables in a constant of both stochastic and time series approaches. That gives an approximate distribution of HC values. The complexity, computational burden, and accuracy are associated with the data of input variables, applied constraints and uncertainties, number of scenarios, power flow simulation tools, and calculation strategy of each approach. The conventional approaches can be used efficiently in small distribution systems with a limited number of operational scenarios to specify the over-estimated capacity expansion during the planning process.

Moreover, the modified approaches are developed to handle the shortcoming of conventional approaches for accurate HC estimation in terms of considering uncertainties and a large number of scenarios without influencing the simulation time. Initially, the optimization algorithms perform baseline power flow data based on system constraints and uncertainties to drive the power flow calculation towards achieving several objective functions at the same time. However, the complexity and computational time are increased with a large number of iterations and complex ADNs that directly influence the obtained HC value. Subsequently, streamlined, hybrid, and other approaches are applied without requiring an accurate presentation of benchmarks and estimate an approximate HC value based on the prior-knowledge equations that verify the system reliability and sensitivity.

Thus, the data-driven methods have superiority compared to other approaches in terms of real-time estimation and forecasting of uncertainties of DERs, generation profiles, load deviation, and power injection. Also, they can combine with other methods to improve their operation strategies with acceptable computational time and accuracy. Moreover, they can be used to predict the behaviour of system variables which helps to avoid fault occurrence or blackouts.

Table 10 gives a brief comparative study of HC calculation approaches. Fig. 8 depicts the research trends of HC estimation approaches according to the statistics of the cited articles. It is obvious that the optimization-based approaches are most popular for calculating the HC (21.25%), due to their accuracy and ability to estimate the accurate HC under various uncertainties and constraints. Followed by the deterministic approaches with around 19.15% are applied to attain fast and approximate HC calculation in the worst-case. Both data-driven and stochastic approaches are almost the same applied percentage (16%) before time series methods that need extreme amounts of historical data which are not provided in old power systems. Finally, the remaining percentages involve both hybrid and other approaches which are developed for special calculation cases.

According to the previous discussion, the authors recommend using conventional HC calculation methods for small and old power systems that include less complexity and a limited number of operational scenarios. While applying optimization, data-driven, and hybrid methods for MPSs with large sizes and high complexity with the high accuracy desired. The authors prefer to employ, in general, hybrid methods to combine the various advantages of both optimization, and data-driven methods, and eradicate their

TABLE 8. Selective studies of optimization-based HC estimation methods.

Ref.	Year	Country or Network type	Algorithm	Controlled PI	HC uncertainties	HC technology	Considering HC enhancement		Study Objectives
							Yes	NO	
[194]	2021	Low Voltage Network Solutions (LVNS) project	Heuristic methodology	PI1,PI3	Capacity and location of heat pumps, EVs, load deviation, power injection	Heat pumps, EVs	✓		R1→ R4
[195]	2021	IEEE 33-bus DS	Slime Mould Algorithm		Capacity and location of PV systems, BESSs, load deviation, power injection	PV, BESS	✓		
[196]	2021	Several ADNs	Manta Ray Foraging optimization algorithm (MRFO)		Capacity and location of DERs, load deviation, power injection	DERs		✓	R2,R3
[197]	2022		Artificial hummingbird algorithm					✓	R2,R3,R5,R6
[198]	2022		GA		Capacity and location of DGs, and capacitor banks, load deviation, power injection	DGs, capacitor banks	✓		R2→ R4
[199]	2022	IEEE 33-bus radial DS	GA, Particle Swarm Optimization (PSO)		Capacity and location of DERs, load deviation, power injection	DERs		✓	R2,R3
[200]	2022	IEEE 123 bus network	Repeated PSO					✓	R1,R2
[201]	2022	18-bus, 33-bus and 69-bus systems	Artificial Ecosystem Optimization (AEO), PSO and Harris Hawks Optimizer (HHO)		Capacity and location of DGs, and BESSs, load deviation, power injection	DGs, BESS	✓		R3→ R5
[202]	2023	83-bus and 135-bus systems	GRASP-TS		Capacity and location of DGs and EVs, load deviation, power injection	DGs, EVs		✓	• R2,R3 • Similar to [203]
[204]	2023	IEEE 33-bus DS	Artificial rabbits' optimization algorithm (AROA)		Capacity and location of PV inverters, load deviation, power injection	PV inverters as STATCOM device	✓		R2→ R4
[112]	2023	30 MVA, 110/35/10 kV substation	GA	PI1,PI2,PI3,PI5,PI6	Capacity and location of DGs, load deviation, power injection	DGs		✓	R1→ R3
[205]	2023	IEEE 33-bus and TNEB 84-bus radial DSs	MOEA/ D-DRA	PI1, PI3, PI7	Capacity and location of DGs, and BESSs, load deviation, power injection	DGs, BESS	✓		R2→ R6
[206]	2023	San Andres Distribution Network Model	Several convex optimal power flow algorithms, PSO	PI1, PI3	Capacity and location of PV, and BESSs, load deviation, power injection	PV, BESS		✓	R3

TABLE 8. ***(Continued.)*** **Selective studies of optimization-based HC estimation methods.**

[207]	2023	IEE 24-bus system	Hybrid sine cosine artificial rabbits	PI1,PI2,PI3,PI7	Capacity and location of DERs, and ESSs	DERs, ESSs	✓		• R1→ R4 • Considering the impacts of transmission lines expansion, fault current limiters on HC enhancement.
[208]	2023	IEEE-33-bus and 69-bus ML test systems	Multi-Objective Advanced Gray Wolf Optimization (MOAGWO)	PI1, PI3	Capacity and location of DGs, ESSs, and FACTs, load deviation, power injection	DGs (PV, WT), ESSs, FACTS	✓		R1→ R4

*PI1:voltage limits;; PI2:thermal overloading; PI3: Power losses; PI4:reverce power flow; PI5: protection limits; PI6: power quality; PI7: Reliability and sensitivity;
R1: Calculating the maximum HC of integrated DERs.
R2: Assessment of the PIs of the ADNs.
R3: Minimizing the total energy losses.
R4: Investigating impacts of HC enhancement techniques (ESSs, FACTS,….).
R5: Minimizing investment cost.
R6: Minimizing CO2 emission.

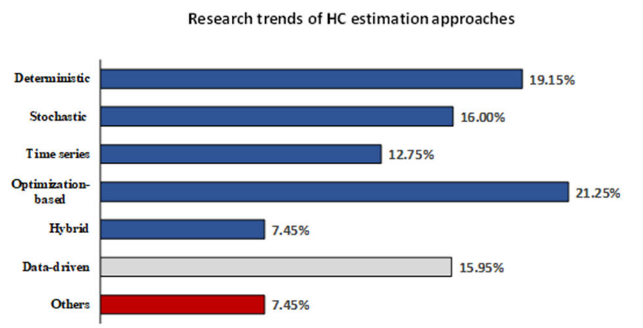

FIGURE 8. **Research trends of HC estimation approaches.**

disadvantages. However, some methods are highly recommended for special systems and calculations according to various research articles at the pervious presentation of HC estimation methods.

VI. TOOLS FOR HC CALCULATIONS

To overcome with complexity, nonlinearity, uncertainty, data diversity, and domestic observability of the modern ADNs due to the increased RESs integration into the UG, several aided tools (software) are being implemented as reviewed in [229]. For HC calculation methods, several software programs are utilized as power system simulation and analysis platforms which are discussed in [12], [57], [230], and [231]. Hence, the selection of a suitable tool for conducting the HC calculation depends on several factors such as the calculation method, controlled PIs, the system construction and complexity, the size of the dataset, required accuracy, etc. for conventional and modified methods of the HC calculations, some platforms can be used for instance; Etab, Matlab [10], [179]; Power Factory, PSS Sincal ICA, NEPLAN, etc. While the data-driven methods can be utilized using Tensorflow, Keras, Caffe, etc, with the aid of several programming languages for example; Matlab, Java, and Python. The information on the tools that will be discussed is based on tool providers and companies from online websites. Some of them are discussed below and other platforms are summarized in Table 11.

A. TOOLS FOR CONVENTIONAL AND MODIFIED HC METHODS

According to the conventional and modified HC methods, several simulation tools can be used in commercial and non-commercial projects, besides Etab and Matlab, as discussed below:

1) POWER FACTORY

Power factory software developed by DIgSILENT company which used for complete electrical power system analysis with different voltage levels in addition to calculating the HC in balanced or unbalanced systems in view of voltage, thermal loading, protection and PQ limits. It used stochastic (based on standard binomial search (SBS)), iterative and time series methods [232]. It is widely applied for studying the PQ of the UG [233], [234], power system stability in [235], [236], [237], [238], and [239], protection requirements in [240], [241], [242], [243], [244], and [245], optimal planning and operation [246], [247], [248], or control and optimization [249], [250]. Hence, it calculates the HC with respect to high-level penetration in PV systems [251], [252], EV charging stations [253], ESSs [254], or RESs [254], [255], [256], [257]. In [251], it is employed for HC calculation and studying HC enhancement due to high-level PV systems penetration in remote industrial microgrids considering UG disturbance and recovery scenarios in the presence of ESSs. Here, the deterministic approach was applied for estimating and assessment of PV HC with respect to over-voltage limits in LVDSs using the PF simulator [252].

TABLE 9. Selective studies of data-driven HC estimation methods.

Ref.	Year	Country or Network type	Method	Controlled PI	HC uncertainties	HC technology	HC enhancement		Study Objectives
							Yes	NO	
[216]	2020	Australian MV feeder supplying 79 LV networks	Smart meter driven	PI1	System parameters	PV	✓		R1,R2
[219]	2021	Australia	Smart meter driven, DNN	PI1				✓	R1→ R3
[16]	2022	IEEE 37-bus and 906-bus systems	Data-Driven Search Algorithm	PI4,PI5,PI6		PV	✓		R1,R2,R5
[220]	2023	Historical data		PI7	Capacity and location of PV, ESSs, EVs	PV, ESSs, EVs		✓	• R3, R6 • Similar to [221]
[222]	2023	IEEE 34- bus, 123 bus systems	Spatial-Temporal DL	PI1	Capacity and location of DERs, load deviation, power injection	DERs		✓	R1→ R3
[223]	2023	Australia	CNN-LSTM	PI6,PI7				✓	R1→ R3, R6
[224]	2023	12 northeastern feeders	Random Forest Model (RFM)	PI1,PI2		PV		✓	R1→ R3
[225]	2023	IEEE-33 bus DS	Histogram-based gradient boost (HGB) algorithm	PI5,PI6,PI7	System parameters	DERs	✓		• R1→ R3 • Fault type detection and location
[188]	2023	EPRI Ckt5 model	Smart meter driven	PI1,PI5,PI6,PI7	Capacity and location of DGs, power injection	PV		✓	• R1→ R3 • Similar to [226]
[227]	2023	33-bus and 152-bus systems	Multi-agent deep reinforcement learning (MADRL) algorithm	PI1,PI3,PI4,PI7	Capacity and location of DERs, and ESSs, load deviation, power injection	Thermal DGs, PV, WT, ESSs, flexible loads	✓		R1→ R6
[228]	2023	Australia	Smart meter driven	PI1	System parameters	PV, EV		✓	R1→ R3

*PI1:voltage limits;; PI2:thermal overloading; PI3: Power losses; PI4:reverce power flow; PI5: protection limits; PI6: power quality; PI7: Reliability and sensitivity;
R1: Calculating the maximum HC of integrated DERs.
R2: Assessment of the PIs of the ADNs.
R3: Predication of operational factors and planning.
R4: Minimizing the total energy losses.
R5: Investigating impacts of HC enhancement techniques (ESSs, FACTS,….).
R6: Minimizing investment cost.
R7: Minimizing CO2 emission.

2) PSS SINCAL ICA

PSS Sincal ICA module offered by Siemens as a tool for electrical power system analysis such as modelling of generation, transmission, DSs, network planning or operation with integrated RESs. Also, it can be used to estimate the maximum HC of LVDSs using time series or iterative methods in terms of various PIs for example voltage limits or protection limits. Although its effective features, it still suffers from long computation times and restricted PI testing [258]. In [259], it is used to investigate the ability to improve distance protection relays for fault detection and discrimination in electrical transmission systems. While in [260], it is applied to study the dynamic stability for isolated electrical power systems considering load variations and DERs uncertainties depending on the frequency control. The authors in [261], discussed the sensitivity analysis of increased uncontrolled HC and its impacts on the UG due to the high penetration level of RESs and utilized ESSs concerns economic uncertainties and the energy market.

3) OPENDSS

The open electric power distribution system simulator (OpenDSS) is a platform developed by and supported by the EPRI for investigating the power system performance operation under the integration of the DERs [262]. It is based on frequency domain simulation that is able to efficiently perform several power system analysis tasks such as planning, protection, stability, and PQ [39], [263], [264], [265], [266]. However, it can't be used for investigating electromagnetic transients in time domain simulations. Also, it is designed to operate and integrate with other varieties of existing software such as Matlab [267]. In [22], it is applied to assess the HC of LVDSs due to the integration of various DERs. In [62], [63], and [64], it is utilized to investigate the maximum HC

TABLE 10. Comparative study of HC estimation methods concluded from [10], [12], and [56].

Item	Conventional					Modified				Data-driven
	Deterministic	Stochastic	WC hour	Time series	CCB	Streamlined	Optimization-based	Hybrid	Others	
Brief description	Fixed input data, generation and load consumption profiles used to calculate HC by modifying DERs capacities in steps until violating PQ limits.	Considering technical and economic uncertainties of input variables then baseline power flow analysis is performed iteratively by gradually varying the capacity and the location of DERs until exceeding the PIs' violation.	Like a deterministic method but it is applied for maximum and minimum hour-period only.	Historical measurement and variable input data, generation and load consumption profiles are used to calculate HC by modifying DERs capacities in steps until violating PQ limits.	Analyzing the historical data of ADNs' parameters based on the capacity constraints of the DERs without considering their uncertainties.	Hybrid strategy based on stochastic and time series methods by simulating a continuously set of prior knowledge equations and parameters depended on baseline power flow until violation of any PI.	Using the input variable data and uncertainties as an optimization problem which is simulated in optimization algorithms to achieve specific objective functions.	Combining the merits of various approaches.	Developed to deal with some obstacles of conventional approaches	Processing the historical dataset or measured data, to develop models for real-time estimation and forecasting the HC
Data requirement	Small	Moderate	Small	Large	Moderate	Moderate	Large	Depends	Depends	Large
Considering uncertainties?	No	Yes	No	Yes	No	Yes	Yes	Depends	Depends	Yes
No. of applied scenarios	Few	Large	Few	Moderate	Few	Moderate	Large	Moderate	Moderate	Extreme
Complexity	Simple	Complex	Simple	Complex	Moderate	Complex	Complex	Moderate	Depends	Complex
Computational time	Small	Large	Small	Large	Moderate	Moderate	Large	Moderate	Depends	Large
Scalability	Easy	Complex	Easy	Complex	Complex	Easy	Complex	Moderate	Moderate	Easy
Output Interpretation	Easy	Complex	Easy	Complex	Complex	Easy	Easy	Easy	Easy	Easy
Model-Based	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Results' accuracy	Approximate	Accurate	Approximate	Accurate	Approximate	Approximate	Exact	Accurate	Accurate	Exact

of RESs during the presence of EV charging systems or ESSs considering several PIs such as voltage limits and reverse power flow.

4) SYNERGI ELECTRIC

Another robust simulation and optimization software called Synergi Electric developed by DNV GL can be used for real system implementations to detect the power DS planning, and reliability [270]. It provides the ability to treat a huge dataset of power systems measurements from SCADA systems to reach the past 10-year period on looped, radial and ring network systems with different voltage levels and configurations. In addition to integrating to estimate the PV HC during stochastic behaviour of EV charging systems and ESSs under various PIs [271], [272], [273].

5) NEPLAN

NEPLAN is a power system simulation platform developed by Neplan AG utilized for investigating various power systems (planning, optimization, analysis) considering different PIs [274]. It simulates the electrical power systems under the existences of various types of RESs, ESSs, and EVs based on stochastic behaviours (using MC simulation) and determines the HC associated with the limiting PIs [275], [276], [277].

6) CYME

CYME is a power system simulator developed by EATON to validate the generation, distribution, transmission and industrial power systems including DERs, RESs, EVs, ESSs, and variable loads [278]. There are two modules for simulation namely ICA and EPRI DRIVE modules which are helpful during estimating the HC. Firstly. The CYME (ICA) module employs both iterative and streamlined methods with a constant source approach to calculate the HC restricted by the PIs' constraints such as thermal loading, reverse power flow, voltage limits, protection aspect, and sympathetic tripping as discussed in [279] and [280]. On the other hand, the CYME (EPRI-DRIVE) modules use a streamlined method which is suitable for HC calculation during MESs especially on EH systems including RESs, and ESSs. The studied PIs can be thermal loading, PQ, voltage fluctuations, protection aspects, and reliability, as applied in [281] and [282].

7) OTHER TOOLS

Several tools are applied to evaluate the power system operation including the increased integrations of DERs and EVs besides examining and determining the various PIs and the HC of RESs and ESSs, as discussed in [229]. Some important tools for instance; EDSA Paladin Toolkit [283], HYPERSIM/ePOWERgrid [284], EasyPower [285], DSA Tools [286], and HOMER [287].

B. TOOLS FOR DATA-DRIVEN HC METHODS

Various tools are developed for data-driven methods such as Tensorflow, Theano, Caffe, Torch, and PyTorch which can be programmed using C, C++, Python, Lua, Matlab, etc; as stated in [10] and [54]. In cooperation with the previous tools, some tools can be used to simulate the power system environment based on data-driven HC methods [10], [22]. In [264], mixed-domain of ML techniques such as RL environment using OpenDSS for the power system and Python package is used for evaluating the cyber-resilient power system. With respect to the increased integration of DERs into the UG,

TABLE 11. A brief survey of HC calculation Software tools summarized from [12] and [57].

Software	Company	Availability	Tool	Method	Controlled PI	Refs.
Power Factory	DIgSILENT	Commercial	Module	Stochastic (SBS method); Time series; Iterative	PI1,PI2,PI3,PI6, and PI7	[233], [235]–[257]
PSS Sincal ICA	Siemens	Commercial / Free trial	ICA module	Time series; Iterative	PI1,PI2,PI3,PI4,PI5, and PI6	[258]–[261]
OpenDSS	EPRI	Open source	Module ; code	depends	depends	[22], [39], [263]–[266], [62]–[64]
Synergi Electric	DNV GL	Commercial	Module	Stochastic (RP method); Time series; Iterative	PI1,PI2,PI3, and PI5	[270]–[273]
NEPLAN	Neplan AG	Free Demo / Commercial	Module	Stochastic (MC method)	PI1,PI2,PI3, and others	[274]–[277]
CYME (ICA)	EATON	Free trial	ICA module	Streamlined (ICA); Iterative	PI1,PI2,PI3,PI5,PI6,PI9	[278]–[282]
CYME (EPRI)			EPRI drive	Streamlined	PI1,PI2,PI3,PI6,PI7, and PI8	
Data-driven platforms such as (EPRI, LTB, Tensorflow,…etc)	Various companies (EATON, Mathworks,….etc)	depends	Dataset; code; module	Data-driven	Depending on the selection from PI1⟼ PI9 and others	[10], [54], [55], [229]

*PI1:voltage limits; PI2:voltage fluctuations; PI3:thermal overloading; PI4: short circuit limits; PI5:reverce power flow; PI6: protection limits; PI7: power quality; PI8: Reliability; PI9: Sympathetic tripping; SBC: Standard binomial search; RP: Random placement;

TABLE 12. Various articles related to solving PQ issues.

Ref.	Year	Research Objectives
[288]	2018	Referring to the PQ improvement techniques, this article discussed the various applicable devices in cooperation with the multi-function DERs in addition to the control strategies and schemes.
[289]	2018	These articles investigated an overview of the various analytical, DL, and optimization approaches to state the optimal location and capacity of the ESSs in the LVDSs besides the control methods to ensure the best operation and to restrict the PQ issues. Similar to these contributions, the authors in [290] discussed the role of BESSs to rise the HC of LVDSs.
[38]	2019	
[109], [291], [292]	2019	The purpose of these articles is to depict an overview of the most prominent techniques to treat voltage violation issues and reduce them to acceptable limits. Also, discussing the impacts of these techniques to increase the HC of the ADNs.
[293]	2020	Studied the various techniques and control systems to enhance the HC with respect to dealing with the power system protection, operation, and stability issues.
[294]	2021	To minimize the effects of increased penetration of the DERs into the UG, various protection coordination schemes were studied from the point of view of their pros and cons, and implementation cost.
[218]	2022	According to the planning and forecasting operation of smart ADNS, this article studied the various ML algorithms for complete EMS implementation in cooperation with EV charging systems, ESSs, and smart meters. Moreover, protection and PQ aspects were considered.
[88]	2022	Studied the techniques of volt-var control to reduce the urgent impacts of high penetrations of RESs into the UG, similar in [295], in terms of network side management (NSM) and demand side management (DSM). Also, the effect of integrating the EVs, DERs, and ESSs in cooperation with the volt-var control techniques was significantly discussed and supported with a detailed comparison in the vision of the current and future challenges.
[296]	2022	To overcome the serious impacts of the voltage violations in the ADNs, as discussed in [52], due to the widespread of power electronic converters equipped with the RESs, conventional and modern techniques to enhance the PQ was investigated besides discussing the role of the PV converters on the reactive power compensation using advanced control techniques based on optimization strategies.
[297], [298]	2023	
[299]	2023	The authors proposed a new transactive energy control (TEC) strategy for EMSs due to the high-level RESs penetration in microgrids with respect to economic, computational, and communication factors, supported by the literature review of TEC approaches for EMSs.
[300]	2023	Referring to MPSs, this article gave an overview of the role of ESSs on MESs to sustain the optimal operation of the UG duration and the high integration of DERs.

the necessity of estimating the short circuit current levels during urgent faults was significantly raised especially with the complexity of simulating complex time domain systems. So, the artificial neural network (ANN) is applied with the aid of DIgSILENT PowerFactory to overcome in [244]. Depending on the dataset of real systems in South Australia, the

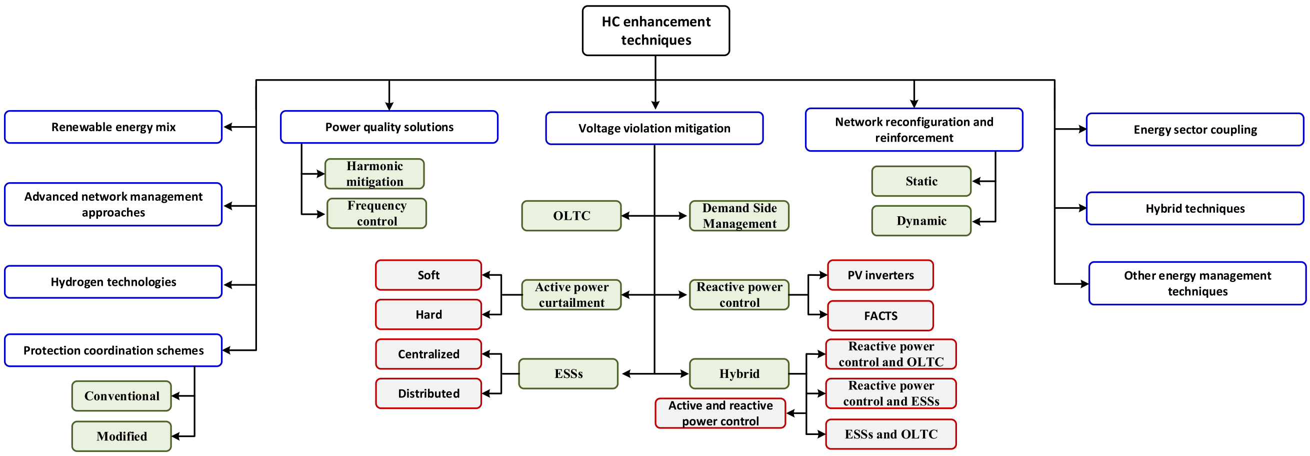

FIGURE 9. Classification of HC enhancement techniques.

PV system curtailment and its influences on the demand side response were analyzed to increase the HC using the data-driven methods [221]. In [225], ML techniques have been used for fault prediction diagnosis (type and location) on reconfigured IEEE-33 bus ADNs developed in Typhoon HIL's real-time environment. Moreover, three DL algorithms were applied to increase the accuracy during calculating the HC through DSs (IEEE 34, 123-bus feeders) using CYME in [222].

VII. HC ENHANCEMENT TECHNIQUES

This section investigates various HC enhancement techniques applied in MPSs to eradicate the PQ issues that are mainly associated with voltage violations and other PIs. Which in turn maximizes the accommodation of DERs without exceeding the technical and economic aspects. Hence, several studies are summarized in Table 12, which investigated the state of the art of mitigation techniques for PQ issues to improve ADNs' operation and reliability. The HC enhancement techniques can be classified into several groups in terms of operation strategy and characteristics, as depicted in Fig. 9.

A. VOLTAGE VIOLATION MITIGATION TECHNIQUES

The most important HC techniques are the voltage control methods as the voltage PI influences directly other PIs. In this sub-section, various classifications of these techniques which depend on the operation topologies, advantages, control schemes, and others, are elaborated as mentioned in [52], [109], and [139].

1) REACTIVE POWER CONTROL

It is assumed that the reactive power influences directly the voltage profiles, so the RPC methods can be used for reactive power support to enhance the voltage index under high penetration DERs in ADNs. Various prominent RPC techniques are employed such as fixed capacitor banks, Var control of PV inverters, and FACTS devices.

a: CONTROL OF PV INVERTERS

By coupling the ESSs with the PV inverters, the combined system can be controlled for active, reactive, or hybrid power support. The RPC using smart inverters can be implemented by three methods namely, reactive power as a function of voltage (QV), PF as a function of PV active power (PF(P)); PF as a function of voltage (PF(V)), and constant power factor. Among these methods, the most common method is the QV method implemented for controlling the PV inverters. Several studies investigated the role of PV inverters to enhance the HC as mentioned in [301], [302], [303], [304], and [305].

b: FACTS DEVICES

Fixed capacitors can be used for RPC to enhance the voltage profile however several drawbacks appear. So, the FACTS devices are extensively used which involve some most common devices in LV ADNs such as SVC, distributed static compensator (D-STATCOM), and unified power flow controller (UPFC), as investigated in [56]. Some studies highlighted the importance of FACTS devices as RPC techniques in [282], [305], [306], [307], [308], [309], and [310].

2) VOLTAGE CONTROL USING OLTC TRANSFORMER

One of the most utilized HC enhancement techniques is the OLTC transformer which can be a single phase or there phases connected in MV or LV feeders [52]. It can regulate the output voltage by changing its turn ratio. Moreover, it is essential to operate in parallel with other voltage control techniques to avoid voltage instability during heavy loads that caused power blackouts [109]. Many articles studied the OLTC transformer as an efficient HC improvement technique for emerging grids in [311], [312], and [313].

3) ACTIVE POWER CURTAILMENT

In the absence of voltage control methods, the APC strategy is implemented to cut off the excessively generated active power from the supply side to tackle the overvoltage problems without influencing the power flow directions and to sustain the energy balance between generation-side, and customers [52]. The APC strategy can be soft or hard curtailment methods [7]. In soft methods, the active power is curtailed partially according to the overvoltage deviations. In contrast, the hard methods curtail the active power completely once the voltage PI is violated. Both of them can curtail the active power with fixed or variable amounts according to the violated PI, generated power, and energy demands. Some DGs like PVs or WTs utilize the maximum power point tracking (MPPT) control technique to regulate the output power according to the energy demands and their stochastic environments, as discussed in [1] and [314]. Several studies employed the APC strategies in [315], [316], and [317], as discussed in the literature review. Moreover, some articles investigated the applications of data-driven methods to forecast the amount of active power that will be curtailed considering the uncertainties of the DERs and predict the other operation performances of the ADNs [318], [319].

4) ENERGY STORAGE TECHNOLOGIES

ESSs are implemented to improve the PIs and enhance the HC by supporting the ADNs with additional active or reactive powers based on control schemes of their charging and discharging modes [52]. So, various optimization techniques are applied for specifying system reliability and minimizing the implementation cost by using the optimal allocation of ESSs in terms of their required capacity and suitable positions, as discussed in [38], [201], [320], [321], [322], [323], and [324]. A comprehensive review of the state of the art of ESSs is established in terms of their topologies, control schemes, technical characteristics, benefits, and others, at both network and customer sides in [38] and [289]. Moreover, the impacts of applied ESSs as ancillary services on the various PIs and their role in enhancing the HC, are explained in [300]. One of the most important roles of the ESSs is performing peak shaving strategy for loads. To overcome PQ issues and reduce energy costs in high energy demand intervals, the peak shaving strategy is used by regulating the energy consumption from the UG and ESSs [300]. Another role of ESSs is to maintain frequency stability by integrating the DERs inverters with them under complete control of active and reactive power exchange which is the same concept of virtual inertia. The impacts of EV charging systems on the capacity of ESSs in standalone microgrids, is investigated in [325].

5) DEMAND SIDE MANAGEMENT

One of the most vital EMSs is demand side management (DSM) which enhances the HC, and the system security and reliability by maintaining the acceptable voltage level and reducing the energy loss. The DSM strategy is defined as a sort of residential load control protocol between the system operators and consumers that stated some action had to be activated to shift the deferrable household loads from the peak hour to off-peak hour such as EVs, and electrical boiler, in order to enhance the PQ and make profits for both system operators and consumers [52]. Also, it specifies the guided code for integrating the generated power from rooftop PV systems of prosumers into the grid. The DSM policy depends on smart PV inverters, voltage enhancement techniques, and DRPs, as elaborated in [88]. Moreover, both smart meters and ESSs are essential to implement besides the PV generation systems, for monitoring the historical data of generation and consumption of each end-user to schedule the energy consumption, however, customer privacy is still questionable. It involves three schemes peak shaving, load shifting, and valley filling which can be applied based on the scheduled energy consumption [109]. Several articles investigated the DSM strategy based on load shifting and DRP in [326], [327], [328], and [329].

6) HYBRID TECHNIQUES

To benefit from the advantages of various voltage control methods and eradicate their drawbacks, hybrid techniques are applied that can be active and reactive power control, RPC with OLTC, RPC with ESSs, and ESSs and OLTC [330]. The selection of various techniques to be combined mainly depends on the generation and consumption profiles, implementation cost, the HC enhancement percentage, required control schemes and their complexity degree, voltage level, and other aspects. Various studies highlighted the contribution of hybrid techniques in improving the HC and PQ in [331], [332], [333], [334], and [335].

B. POWER QUALITY SOLUTIONS

Besides the voltage violation mitigation techniques, the PQ solutions based on harmonic mitigation and frequency control techniques are investigated as HC enhancement techniques [56]. The frequency control methods are applied for frequency stability especially in the presence of non-dispatchable generation units in the MPSs by using virtual inertia power plants as an example [336]. Relative to the presence of non-linear loads and power electronic converters, the harmonic distortion should be declined to enhance the PQ using various types of filters as discussed in [288]. Hence, the passive [337], [338], [339], [340], [341], active [342], and hybrid filter [343], [344] configurations can be used to mitigate the THD level in the ADNs due to DERS-rich integration. Other techniques can be used also for enhancing the PQ such as voltage regulators and restorers, FACTs, smart impedance, hybrid, and others [288].

C. PROTECTION COORDINATION SCHEMES

The protection systems can tackle the bad effects due to the high penetration DERs, ESSs, and EVs, using devices or control strategies as deliberated in [52] and [294]. The protection systems have to respond efficiently to the various coordination obstacles because of bidirectional power flow, excessive faults, variations of integrated component capacities, and operating modes (grid-connected or islanded), without causing misoperation of both protection devices' functions and control schemes. To sustain the ADNs' reliability and stability and enhance the HC, various protection strategies are implemented which are classified into conventional or modified techniques.

1) CONVENTIONAL PROTECTION STRATEGIES

Conventional protection strategies handle the initial arrangements that should be considered before occurring probable protection issues. Firstly, the DERs disconnection can be applied if there is an excessive generated power and then reconnecting them under UG standards. Second, the strategy based on the optimal allocation of DERs is significantly helpful to avoid adverse impacts on the protection systems. Other auxiliary strategies can be implemented such as applications of ESSs and modifications of control schemes.

2) MODIFIED PROTECTION STRATEGIES

In contrast, modified strategies depend on modifications to the functions of protection devices and applied control methods and variables. Advanced protection relays can be used such as differential relays to provide new functions. Moreover, applied control methods and variables are utilized by symmetrical components, voltage-based, signal processing and AI techniques, alternation on relay parameters, and other electrical parameters. Some protection strategies are designed to combine both conventional and modified schemes. Hence, several articles investigated the coordinated control schemes for PV inverters with reconfigured networks in [345], [346], [347], and [348], and optimization of EV operation in [349], to treat the declared protection system issues.

D. NETWORK RECONFIGURATION AND REINFORCEMENT

Network reconfiguration and reinforcement (NRR) techniques contribute to enhancing the HC by reducing the overall system energy loss and voltage violations which effected directly on the end-user feeders [350]. In these techniques, the network configuration is modified by changing the DERs' location and capacity and loads and their connection among phases. Then the RL algorithms are utilized to regulate the process of network reconfiguration in order to maintain the system's reliability and efficiency. The network reconfiguration can be static or dynamic [351]. In the static approach, the modifications on the networks are acted on using fixed parameters. Regarding the dynamic approach, the statutes of controlled switches or components, and capacities and locations of DERs, ESSs, EVs, and loads, are changed as a function of time using online monitoring devices and systems such as SCADA. Several studies have applied the NRR strategy by allocating several system components to improve the HC in [194], [208], [352], [353], [354], [355], [356], [357], and [358].

E. ADVANCED NETWORK MANAGEMENT APPROACHES

By applying new control techniques for energy management, the HC is enhanced and the ADNs reliability is improved [56]. Hence, the ANM approaches depend on the communication infrastructure to implement centralized, distributed, and decentralized controllability with the help of system parameters' measurements. These approaches can be combined with other HC enhancement techniques to increase the merits however they require more attention to avoid their drawbacks on other systems parameters that may be performed maloperation of protection devices [359], [360], [361]. In [333], [362], and [363], the ANM approaches are applied for coordinate control and planning of various components, such as ESSs, OLTC, and EVs, based on the ADNs with integrated DERs under their uncertainties. While in [364], [365], and [366], fact-acting devices like PV inverters, and EV aggregators, are used to perform coordinated control for minimizing energy loss and sustaining optimal operation. Reactive power and voltage control schemes, NRR techniques, and other techniques are merged for planning and managing efficiently the energy exchange in the ADNs, which are considered in [367] and [368].

F. RENEWABLE ENERGY MIX

By implementing several types of energy resources in the MPSs, PQ and other performance conditions are improved and fulfilled the energy demands with high efficiency and economic and environmental benefits. To minimize annual energy loss, the optimal allocation of several generation units of RESs (WTs, PVs, thermal DGs) in [369], [370], [371], [372], [373], [374], and [375]. Other fossil fuels with RESs are combined to accomplish the energy balance [376]. Moreover, nuclear energy is used with RESs or EVs to optimize the power grid operation [376], [377].

G. HYDROGEN TECHNOLOGIES

According to the energy transition policy, low-carbon technologies are implemented such as hydrogen ESSs [378]. To treat the performance violations due to the increased DERs' integration in the ADNs, large-scale hydrogen ESSs are coupled with the DERs which are considered promising technologies [379]. Which can reduce the worst environmental impacts, improve the grid's operational performance, exchange the energy to accumulate a large amount of energy to provide energy demands for a long time, especially during operation disturbances, and have other beneficial aspects [380]. In [381], [382], [383], [384], and [385], the state of the art of hydrogen technologies are reviewed in terms of applications, control systems, economic vision, challenges, and future directions. Several studies are concentrated on calculating the HC of hydrogen ESSs, that are integrated with various DERs and EV charging stations, in ADNs by optimizing their size and placement in [386], [387], [388], [389], [390], [391], and [392]. Hydrogen technologies are considered promising research directions to increase the HC in ADNs.

H. ENERGY SECTOR COUPLING

Relative to the energy market, it is essential for energy management to use various sorts of energy sources and ESSs at the level of service providers, and prosumers to gain economic benefits and enrich the investments in this sector. The energy sector coupling (ESC) strategy performs the optimal planning and scheduling for the energy sources and other power systems components based on the energy demand and generated capacities, especially in the MPSs with high levels of DERs integrations. By adding smart meters, the ESC strategy improves the energy efficiency of the consumers using the demand-side response program with the change to make profits [393]. Moreover, the energy management is optimized on the network side which helps to avoid blackouts and other grid disturbances. In [394], the flexibility of ESC strategy is investigated using business models for prosumers in the energy market. While in several optimization techniques are used for power system planning using several economic policies based ESC approach to maximize the profits of both prosumers and service providers in [395] and [396].

I. OTHER ENERGY MANAGEMENT TECHNIQUES

Various HC enhancement techniques are merged to perform a new hybrid robust technique as mentioned in [397], [398], and [399]. However, more modifications in the energy management techniques are still required to enhance their producers and combine other techniques with them. By usage expansions of MESs, the EH concept is extensively applied for establishing a robust framework to optimize the generation and consumption of various DERs, ESSs, EVs, and other MESs in ADNs [153]. The EH has the ability to provide the electrical, cooling, and thermal demands for consumers with high efficiency and low cost. Further, the increased penetration of ESSs and EV charging systems requires to optimize their capacity and placement to attain the best operation without influencing the PQ [400], [401], [402]. So, special EMSs are developed to deal with the integration of the previous components in the MPSs as highlighted in [403], [404], [405], and [406]. These techniques may depend on data-driven approaches that are helpful in maintaining the better operation performance of ADNs, planning the grid growth, and forecasting the operation PIs to avoid PQ issues and power outages.

J. SUMMARY

Table 13 discusses selective articles on HC enhancement techniques for the past three years. Moreover, Fig.10 depicts the research trends of HC enhancement approaches according to the statistics of the cited articles. Regarding the previous discussion, the most prominent HC enhancement techniques which are applied for voltage control methods presented the highest percentage at 33.94%. These methods may use PV inverters and FACTs which require more attention to apply. While the application of OLTCs, ESSs, DSM, and hybrid techniques is popular, the implementation cost should be considered. Moreover, the energy curtailment techniques are applied to maintain the acceptable operation of ADNs, however, the output power loss (total amount of curtailed DERs' active power) on the end feeders connected to the DERs increases more than others. So, droop coefficient schemes should be implemented. The PQ solutions, and protection coordination schemes recorded 8.26% and 4.59% of total cited articles, respectively. They are important to maintain both the THD and frequency within acceptable limits and avoid the maloperation of protection devices. Hence, both soft and hard network configuration schemes (8.26%) come into the picture to enhance the HC by re-phasing and optimizing the size and location of DERs, EVs, and ESSs that combined with the ANM strategies (11%) for accomplishing the best operation. The renewable energy mix and energy sector coupling policies percentages are 6.42% and 3.77%, respectively. These schemes are vital to support the energy transition policy in the energy market that reduce carbon emission, provide various energy demands, and make profits for both system operators and consumers. Further, the hydrogen technologies for ESSs (10%), reveal promising industrial applications to be integrated into the ADNs. Other EMSs (13.76%) are developed for special HC enhancement applications and to deal with the MESs and EVs in the EHs.

VIII. MODERN POWER GRID OPERATION

To enhance the operation of MPSs, several terms for new technologies that are developed besides the explained HC technologies will be deliberated in this section.

A. ENERGY TRANSITION

To reduce the climate change impacts, the global community takes steps toward replacing the conventional sources that produce large amounts of CO_2 emissions. So, the implementation of MPSs should have the capability to treat the increased penetration of DERs and limit CO_2 emissions without influencing the consumption demand [408], [409]. All these efforts are concluded under the energy transition concept which is defined as "using accessible technologies and spread knowledge or activities to develop the power grid structures by replacing the conventional energy sources

TABLE 13. Selective articles on HC enhancement techniques for the past three years.

Ref.	Year	Country or Network type	Controlled PI	HC estimation method	Applied software, tool	HC technology	Applied HC enhancement technique	Studied objectives
[373]	2020	IEEE 33 bus DS	Voltage deviation, power loss	Optimization-based	Matlab	DERs	DER mix	Allocating the various DERs to minimize the power loss and voltage deviation using a multi-objective optimization problem.
[346]	2020		Voltage deviation, power loss, thermal overloading of feeders and transformers, harmonic distortion, mal-operation of protection devices		Matlab, Hardware-in-loop	PV	NRR	The protection problems and PQ issues are solved using both optimization techniques on the reconfigured network.
[330]	2020	33-bus and 123-bus DSs	ESS investment cost	Stochastic and Optimization-based with Data-driven	Matlab / YALMIP combined with MOSEK	PV	OLTC, ESSs	Studies the reliability and economic impact of ESSs planning with the OLTC during the high penetration of PV systems using various HC calculation methods. Hence, the ESS investment cost was reduced compared to other methods.
[221]	2021	South Australia	Voltage deviation	Data-driven	-	PV	APC	Data-driven methods are applied to analyse the PV system curtailment and its influences on increasing the HC using the dataset of real systems in South Australia with respect to the demand side response.
[387]	2021	15-bus IEEE scheme	Voltage deviation, power loss	Optimization-based	MATLAB/Simulink	RESs	Hydrogen ESSs	Optimizing the optimal location and size of the DERs and hydrogen ESSs.
[333]	2021	IEEE 69-bus DS	Voltage deviation		MATLAB	PV	ANM using OLTC, RPCdevices, EVs	A new coordinated control scheme was developed for energy management in the existing various integrated components to enhance the HC. A similar strategy was applied for WTs in [364].
[337]	2021	Benchmark	Voltage deviation, power loss, harmonic distortions, filter cost			DGs	PQ solutions	Four objective functions are optimized using PQ solutions (passive filters).
[316]	2021		Voltage deviation, power loss, thermal overloading		CPLEX under Python (DOcplex)	EV charging systems, PV	APC	Optimizations of the operation of EV charging systems and PV inverters to mitigate the voltage rise based on the APC strategy. Similar to [315].
[329]	2021	IEEE 37-bus DS	Voltage deviation, power loss, cost		GAMS and MATLAB	EVs	DSM	Regulating the exchanged power between customers and service providers in the presence of EVs and load variations.
[312]	2022	6-bus distribution system	Voltage deviation, power loss	Data-driven	OpenDSS	PV	OLTC transformer	Implementing OLTC transformer to enhance the HC.
[328]	2022	Modified IEEE 15-bus distribution network.	Voltage deviation, power loss, cost	Optimization-based	-		DSM	Stating the load-shifting strategy to enhance the HC.
[323]	2022	IEEE 123-bus DS	Voltage deviation, power loss, cost	Optimization-based	Time-series framework	DGs	BESSs	Optimizing the capacity and placement of BESSs to improve the HC and reduce power loss.
[324]	2022	IEEE 33- and 69-bus distribution systems			MATLAB			
[201]	2022	18-node, 33-node and 69-node DSs						
[317]	2022	LV system	Voltage deviation, power loss, frequency	Another approach based on the MPPT algorithms		PV	APC	Advanced control technique applied for effective regulation of PV inverters based on APC strategy to reduce the voltage rise.
[356]	2022	IEEE 37-bus distribution network	Voltage deviation	Optimization-based	-	DERs, EV charging stations, heat pumps	NRR	3 stages of planning strategy based on NRR technique for load re-phasing of three or single phase lines and varying the allocation of the DERs to reduce the voltage unbalance and maximize the HC. Similar to [194].
[407]	2022	Modified 33-bus and 69-bus DSs	Voltage deviation, power loss, harmonic distortions		-	PV		Both the HC and PQ of high harmonic-polluted ADNs are improved using the NRR technique by optimizing the location and the size of DERs. Similar to [352], [358].
[347]	2022	Southern California	Voltage deviation, thermal line loading	Time series	OpenDSS, Hardware-in-loop	PV	Coordinated control of PV inverters in the presence of capacitors banks	Achieving optimal power flow using new coordinated control schemes of PV inverters in dependence on load variations and feedback correction of measurement devices. Similar to [348].
[388]	2022	Saudi Arabia	Cost	Optimization-based	HOMER	PV, WT, EV, battery and hydrogen fuel-cells	Battery and hydrogen fuel-cells	Reducing the operation cost.
[349]	2022	EV Systems	Battery state of charge and fuel economy	Data-driven	Matlab/Simulink, Hardware-in-loop	EV	Online coordinated control strategy of EVs	Optimizing the economic benefits and performing the optimal operation of EV systems based on online coordinated control methods.
[375]	2022	Al Ashkharah-Oman	Voltage deviation, power loss	Optimization-based	MATLAB, HOMER	DERs	DER mix	Optimal allocation of DGs and RESs to enhance power system operation. Similar to [374].
[389]	2023	Hydrogen Integrated Energy System	Voltage deviation, power loss, investment cost		MATLAB	PV, WT, BESSs, MESs	Hydrogen ESSs	Optimal allocation of hydrogen ESSs for economic profits. Similar to [386], [392].
[390]	2023	Southwestern China	Cost, risk constraints	Data-driven				
[391]	2023	IEEE 33 bus DS	Voltage deviation, power loss, investment cost	Optimization-based	MATLAB/Simulink	RESs	Hydrogen ESSs	
[208]	2023	IEEE 33-bus and 69-bus DSs	Voltage deviation, power loss, harmonic distortions		-	RESs	NRR, ESSs, voltage regulators, SVCs	The HC is enhanced by reinforcing the ADNs using NRR strategy using other enhancement techniques. Similar to [353]–[355].
[357]	2023	City of Terni, IEEE 70 bus DS	Voltage deviation, power loss, investment cost		-	EV charging stations	NRR	New planning strategies are applied to increase the HC by allocating the EV charging stations.
[363]	2023	Modified IEEE 15-bus and IEEE 33-bus distribution systems	Voltage deviation, power loss		GAMS software	PV	ANM-based RPCusing SVCs	The coordinated control scheme is implemented to enhance the HC by optimizing the size and location of SVCs.
[313]	2023	Slovak Republic	Voltage deviation, power loss, thermal overloading	Time series	OpenDSS		OLTC transformer	Implementing OLTC transformer to enhance the HC.
[305]	2023	City of Cuenca		Optimization-based			RPC	Enhancing the HC using the smart inverter control method for reactive power support.
[304]	2023	IEEE 33-bus and 69-bus DSs			MATLAB			
[308]	2023	IEEE 33-bus ,69-bus , and 85-bus DSs			GAMS software and MATLAB	-		Implementing both D-STATCOM devices and capacitor banks to enhance the voltage profile and HC.
[310]	2023	IEEE 13- and 33-bus distribution systems			-	DGs		

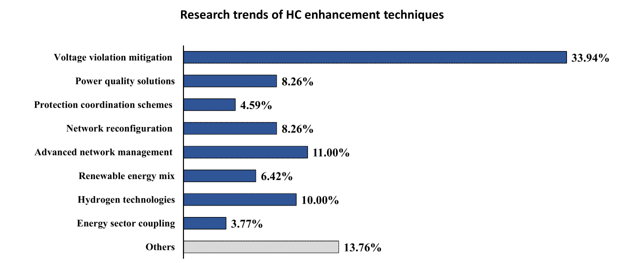

FIGURE 10. Research trends of HC enhancement techniques.

with RESs with concerns of energy balance and economic aspects''. This term was first announced by US President Jimmy Carter in 1977 after the oil crisis in 1973. The term involves several policies namely energy conversion of out-aged power systems and industrial applications, applying RESs, and using sustainable transport vehicles or other sustainable energy applications. In Fig. 11 (a), the energy contribution percentage of various energy resources in the global energy consumption in 2022, is demonstrated. Which, fossil fuels still sustain an excessive percentage about 55% of the total energy consumption followed by hydropower sources (about 15%). Hence the RESs achieved about 22% that requires to be increased in the future. Fig. 11 (b) shows the proportions of total electricity production from RESs per country. China comes in the first top countries that employed large stations' capacities of RESs about 1.16 terawatts, followed by the USA with 352 gigawatts and the remaining countries contribute 91.25% [5]. If the policies of the energy transition are considered, various bad environmental impacts will be reduced in the upcoming decades.

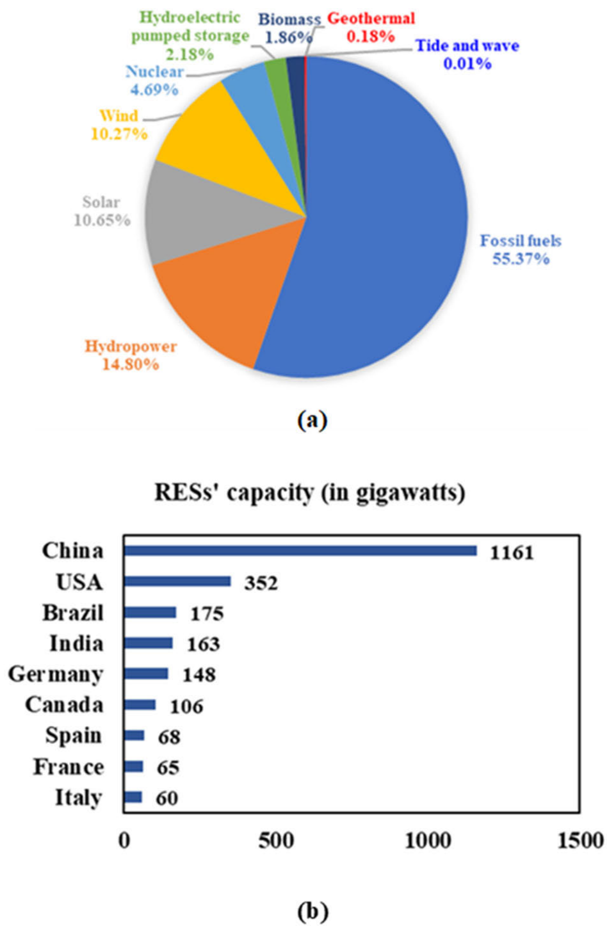

FIGURE 11. Statistics of energy resources consumption and generation in 2022.

B. UNIT COMMITMENT PROBLEM

As a result of spreading the thermal DGs which depend on fossil fuels, optimization, and scheduling of these DGs are challenging task need to be considered in the energy management schemes which are known as unit commitment problems (UCPs), as discussed in [410]. Regarding the developments of MPSs, advanced computational techniques should be applied to optimize the UCP that involves new DERs, ESSs, and EV charging stations with their uncertainties and technical and economic constraints. With the cooperation of the HC concept, the UCP is required for energy management methods using advanced optimization techniques [411]. Moreover, the UCP is a robust tool for energy markets as it is used to minimize the cost of MPSs' components, capital costs and fuel or natural gas costs.

C. LOSS SENSITIVITY ANALYSIS AND VIRTUAL INERTIA INCREMENTAL

Corresponding to the operation performance, two prominent concerns are applied in the MPSs namely loss sensitivity analysis (LSA) and virtual inertia incremental, due to the increased integration of modern components and generation units. It is obvious that the LSA framework was associated with power loss problems in the past which are increased in the MPSs. Nowadays, LSA is not only required to regulate the integration of DERs, ESSs, and EVs as a planning framework but also for operational applications, as elaborated in [412]. In the LSA, the power loss can be classified into technical and non-technical losses. The technical losses are associated with the physical system component properties which include losses of distribution and transmission systems due to component resistance, and other losses, on the other hand, the non-technical losses are dependent on the accuracy of protection devices or smart meters. Several analytical and optimization solutions are used for load flow analysis based on the LSA. The LSA is a powerful concern that should be taken into account during energy management and HC calculation.

In the extreme presence of non-dispatchable generation units (such as RESs) that require power electronic converters, the power system inertia is decreased which in turn in causing frequency instability as reviewed in [336] and [413]. Therefore, the virtual inertia compensation algorithms are implemented with the inverters to improve the frequency stability in low-inertia ADNs, as discussed in [105], [106], [107], and [108]. Before calculating the HC value, it is essential to regulate the virtual inertia compensation techniques.

D. COMMUNICATION INFRASTRUCTURE

For complete controllability in the MPSs, a powerful communication infrastructure should be installed to link all power system components (such as smart meters) together with high accuracy and compact implementation cost. The communication architectures, including wired, wireless, satellite, or power line communication infrastructure networks, interconnect the MPSs with all stages (generation, transmission, distribution, and prosumers) with the energy markets, operations, and service providers [414]. Moreover, the communication architectures should provide easy and effective information exchange among various components of MPSs, real-time system monitoring for operation performance and any small disturbance using cyber-physical systems, and decentralized decision-making in cases of conflicting objectives. The state of the art of communication infrastructure is reviewed in terms of classifications, methods and standards, and enhancement implementation strategies in [415].

E. EMERGING POWER GRID

In cooperation with the HC technologies and previous terminologies, the emerging power grid ensures the integration of various smart power system components with different voltage levels under decentralized control to achieve profits for both customers and utilities. The included subsystems can be classified as smart infrastructure, information, protection, energy management, and data communication subsystems, as discussed in [53]. The smart infrastructure systems secure the power flow at various stages with complete controllability using the information from smart meters and advanced communication systems (5G, Internet of Things (IoT)). Further, the integration optimization of DERs, ESSs, and EVs contributes to decreasing power loss and providing energy demands for consumers. The protection systems with virtual power plants enhance the PQ and ensure frequency stability. While the EMSs (such as EHs) support the power system operation using advanced AI and data-driven techniques. All previous considerations should be in emerging power grids to deal with the adverse impacts of their components.

IX. ENERGY MARKET

In the previous section, most technologies and strategies are applied to optimize the operation of MPSs which contribute to economic dispatch for energy markets. The energy market regulates the various energy sources and specifies their cost. According to global energy statistics, the energy market is predicted to incremental growth as the energy demands (electrical, cooling, and thermal) will increase. Also, it is expected that energy sources will be attained using cleaner and sustainable sources such as RESs. So, the future directions of the energy market can be summarized as;

- Expansion of the RESs in the MPSs to reduce the dependence on fossil fuels which will reduce the bad environmental impacts. So, new technologies should be adopted to adapt the operation of RESs with acceptable quality and low implementation costs.
- The progress of nuclear energy will be associated with the country's economy mainly as the high operation and implementation cost with robust protection systems.
- The industrial communities will face more challenges and pressures to fulfil their obligations towards the energy transition policy. Which obligates them to decline the usage of fossil fuels and utilize the RESs with ESSs. Also, the interruption of oil costs globally may affect positive or negative factors dependent on the oil cost compared to the implementation cost of alternative energy sources.
- Nowadays, the global energy crises and current wars (Russia-Ukraine war) highlight the importance of utilizing extensively alternative energy sources in various countries' policies. So, it is expected the cost of RESs and ESSs will be decreased in the long-term vision.
- The energy management strategies (EHs) supported with HC enhancement techniques will be utilized extensively to regulate the integration of DERs, ESSs, and EVs in the MPSs. These strategies will have obligations on supplying the various energy demands with acceptable energy prices and PQ by minimizing power loss and upgrading the power system infrastructure.
- The development of ESSs will influence the implementation of RESs. So, new industrial technologies should be developed for ESSs to minimize their implementation cost.
- Hydrogen technologies are forecasted to be increasingly integrated into industrial applications especially hydrogen ESSs.
- The widespread applications of EV charging systems will significantly influence the PQ and their interaction with the RESs which should be considered and studied in various grid standards. In addition, the usage of EVs is expected to continuously grow so, the convention transport means that the use of fossil fuels will reduce which helps reduce carbon emissions and other environmental influences.

To sum up, the energy market depends on several factors that specify the contribution and cost of each energy source to be consumed.

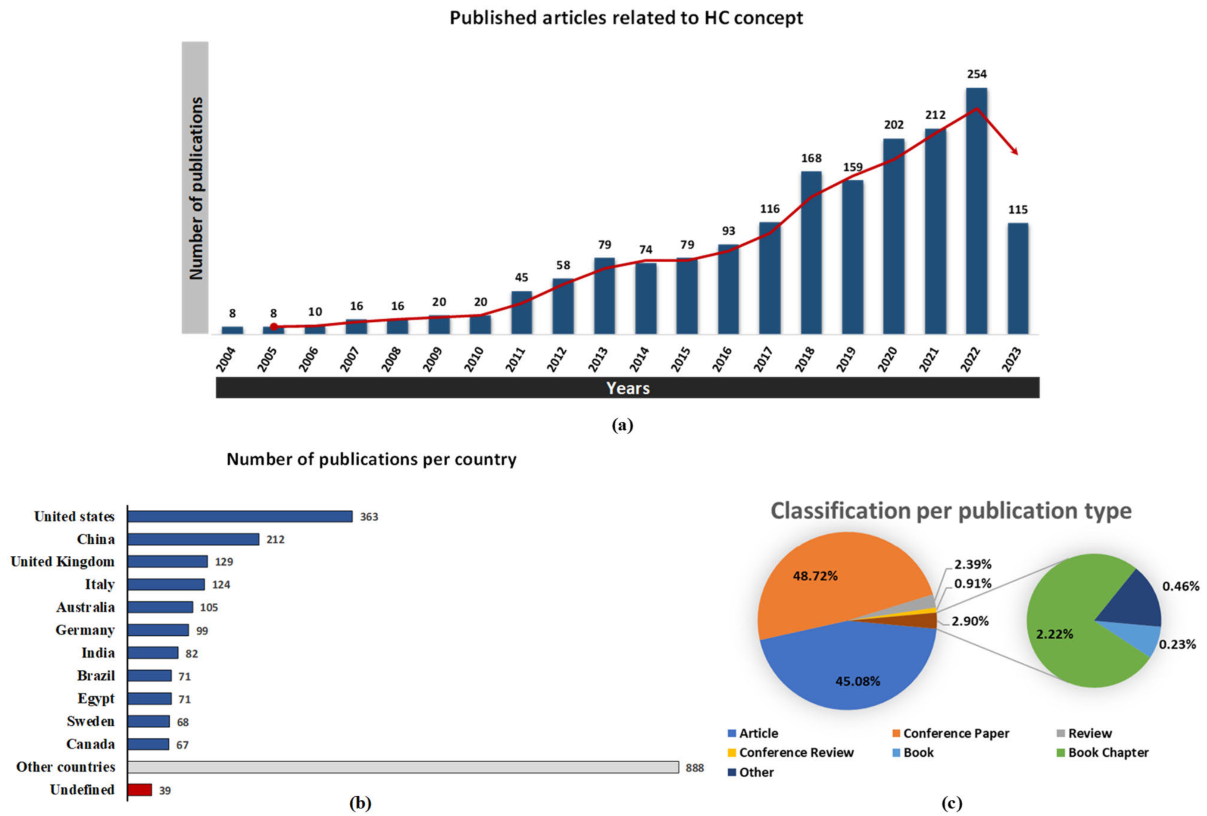

FIGURE 12. Research trend of HC concept.

X. DISCUSSION

A. RESEARCH TRENDS RELATED TO HC CONCEPT

The HC concept was developed in 2004 as an alternative expression of maximum integrated generation units and has been widened in the MPSs to regulate the power exchange without interruption in the operation limits. According to the Scopus database, the most relevant documents based on the HC concept over the past 20 year-period are about 1757 published documents. Hence, the increased trendline is observed over the statistics per year of the published documents, as portrayed in Fig. 12(a). In Fig. 12(b), the contribution of top countries to the published documents is shown. In which the United States comes in the first rank with 363 documents followed by Chine which recorded around 212 documents. Besides the big industrial countries, the small and developing countries are sharing the promised percentage of published articles like Egypt. This proves their determination to implement alternative energy sources for fossil fuels to deal with their economic crises. Regarding the various publication sorts as illustrated in Fig. 12(c), the conference papers and articles are recording the high ratios around 48.72% and 45%, respectively. The remaining proportions are specified for other publication sorts.

B. PERSPECTIVES FOR PROMINENT CHALLENGES

With increased applications based on the HC concept, various significant challenges have appeared, as depicted in Fig. 13. In this section, the most important challenges with their proposed solutions are discussed using the following items;

- Data Availability: for calculating the accurate value of the HC and selecting the suitable enhancement technique, both accurate historical data and measurements should be available. The data include the system parameters, characteristics of DERs, ESSs, EVs, and other components with their uncertainties, generation and consumption profiles, and network topology. Unfortunately, the lack of data availability and data sharing, are the main challenges, especially in the old power systems.

So, advanced HC estimation methods are implemented which depend mainly on the updated data of various system components gained from smart meters, and analysis of them using the data-driven methods with the capability to predict the generic operation performance of the MPSs. Also, a powerful communication infrastructure should be installed to instantaneously take actions related to system behaviour and power flow simulations. Some decentralized control strategies are applied in remote grids depending on local measurements.

- Complexity: the accurate HC estimation is based on the data availability, number of simulation scenarios, and iterations, involved PIs, simulation framework, and size of ADNs. Which increases the complexity and accuracy of applied software that will lead to miscalculations of HC. So, optimization-based and

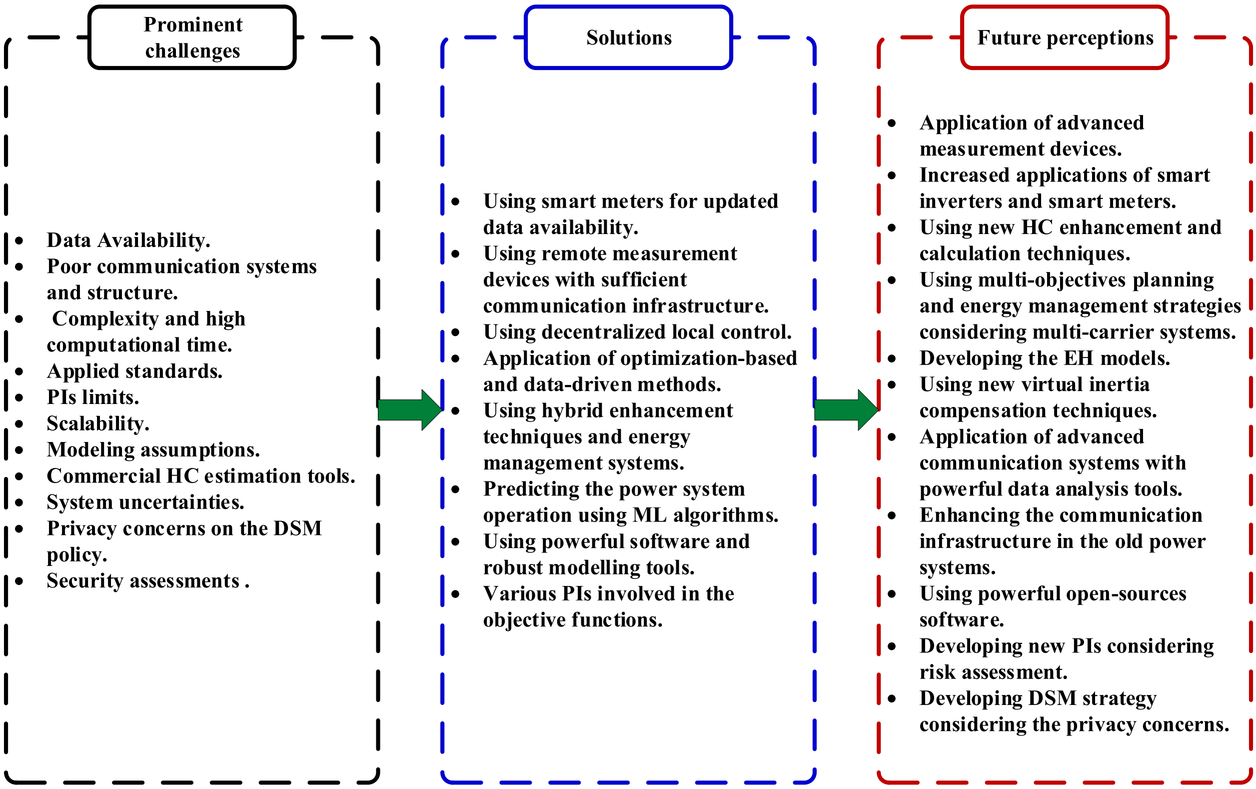

FIGURE 13. Brief description of HC challenges, solutions, and future technologies.

data-driven methods should be applied in cooperation with time-series methods to overcome these drawbacks. Good system presentations with their uncertainties and constraints, and applications of powerful software with robust data analysis capability, are helpful to reduce the complexity and computational time.

- Applied standards: the HC calculations require defining the limiting constraints of variables which depend on the international standard for each region. These standard differences cause challenges in HC estimation to achieve the requirements for the target place.
- Scalability: recognizing the ability of ADNs to adapt to the increased penetration of DERs, ESSs, EVs, and other components, is a challenging task in HC calculation especially in conventional approaches. So, the data-driven methods are suitable for highlighting the scalability of HC calculation.
- Modelling assumptions: to reveal the real operation scenarios in HC calculations, all required system parameters of various variables should be accurately recognized. However, this can't happen due to the increased system complexity, even a high number of iterations and scenarios are used to calculate the HC. Hence, several assumptions are utilized to reduce the complexity and speed up the power flow analysis to gain the approximate HC value. These assumptions depend mainly on the judgment and experiences of system operators.
- System uncertainties: all system uncertainties should be considered in estimating the HC such as uncertainties in generation and consumption profiles, DERs, EVs, and others. Which influence directly on the complexity of system modelling and HC calculation.
- Communication systems: for performing centralized control and observing the online variations of HC, powerful communication systems need to be installed as monitoring all system variables with gaining updated at each time using smart meters. Unfortunately, this is not available for conventional systems.

C. FUTURE TECHNOLOGIES OF HC CONCEPT: PERCEPTIONS AND OUTLOOKS

The analysis of the HC concept is vital for ensuring the safe and reliable operation of the ADNs. In this sub-section, the future technologies related to the HC concept are demonstrated as follows,

- For an accurate definition of system parameters during the HC calculations, several PIs should be included in the modelling tools and objective functions of optimization-based for monitoring the power system operation. Also, new PIs have to be investigated for assessing the HC.

- New HC calculation and improvement methodologies are being developed to address the economic and technical challenges which are detected in the current methods.
- Using new techniques for monitoring the system performance will increase data availability.
- Advanced HC estimation approaches based on data-driven approaches can be utilized to modify the strategies of the conventional and modified approaches with concerns of computational time and accuracy especially in complex ADNs involving various DERs with uncertainties, communication failures, and risk assessments.
- Expansion of applying the data-driven approaches on forecasting the assessment of various PIs, suitable enhancement techniques and their process (predicting the curtailed active power in APC strategy), the generation and consumption profiles under uncertainties, and other operation performance of ADNs.
- Estimating the accurate HC value momentarily using powerful software for power flow simulations that is integrated with smart meters which are used for monitoring and measuring the system parameters.
- Extreme applications of enhanced ESSs for HC improvements especially supercapacitors devices, hydrogen technologies, and thermal ESSs in the EH, that are integrated with advanced control schemes.
- Developing advanced DSM strategies to regulate the power exchange between prosumers and system operators in the presence of EVs and rooftop PV systems.
- Privacy protection and security should be considered through the DSM policies. In addition to protecting the service providers from cyber-attacks that may cause disturbances in the power supply for customers.
- Applying a zero-export power strategy that aims to prevent any generated power from being exported to the UG and consumed on-site or stored locally. Moreover, the DSM policies should involve the worst-case situations, especially the sudden large load interruptions near the feeders connected to the DERs and ESSs, besides regulating the power exchange in the existence of EV charging stations.
- Investigating new control strategies for reactive power support based on smart inverters and coupled ESSs.
- Using multi-objectives planning strategies for DERs, EV charging stations, and ESSs considering the demand response and other HC enhancement techniques, towards low carbon emission MPSs.
- Expansion of using the virtual inertia compensation techniques for frequency stability control in ADNs.
- An extensive investigation based on the collaboration effectiveness of EVs, ESSs, and MESs on the system reliability and performance.
- Developing data-driven control design methods for optimal autonomous controls of the ADNs using advanced optimization, and ML techniques with the account of the limited and cost-effective commutation structure and unpredicted environmental circumstances.

The brief conclusion of the future research trends is summarized in Fig. 13.

XI. CONCLUSION

The necessity for substituting fossil fuels and the evolution of environmental apprehensions are the main motivations for green energy growth in the MPSs. So, various types of DERs are being developed to decrease the worst environmental impacts and support the global demand for electrical energy. However, the continuous penetration of the DERs, EVs, and ESSs into MPSs (MPSs) may cause several adverse impacts endangering the PQ and reliability in ADNs. To deal with these shortcomings, the HC concept is applied to optimally estimate the maximum capacity and suitable location of DERs, EVs, and ESSs without violating the technical and economic limiting constraints. However, centralized optimal energy management and control require extensive communication infrastructure, which is hardly offered without clear financial benefits. In this article, the urgent necessity of a new HC definition is discussed in terms of the incorporation of various significant factors and elements for the MPSs. Firstly, the historical developments of HC definitions, PIs, and estimation methods for ADNs with the high-penetration level existence of the DERs, ESSs, EV charging systems, and multi-energy carrier systems to deal with electrical, thermal, and cooling demands, are studied. Secondly, the authors deliberate the recent approaches for assessing and enhancing the HC, especially regarding the data-driven methods, with supporting various software for simulating real systems. Thirdly, recent research trends and major factors of modern power grid operation are considered with an overview of current developments in energy markets. Fourth, various prominent challenges, current status, and future research trends are discussed. Finally, this review article has appeared to demonstrate an appropriate reference for comprehensive research trends in HC estimation and optimization based on ADNs.

APPENDIX

NOMENCLATURE

ADNs	Active distribution networks.
AGC	Automatic generation control.
AI	Artificial Intelligence.
ANN	Artificial neural network.
ANM	Active network management.
ARIMA	Autoregressive integrated moving average.
ARMA	Autoregressive moving average.
CB	Circuit breaker.
CCB	Capacity constraint-based.
D-STATCOM	Distributed static compensator.
DER	Distributed energy resource.
DG	Distributed generator.
DL	Deep learning.
DRIVE	Distribution resource integration and value estimation.
DRP	Demand response program.

DS	Distribution system.
DSM	Demand side management.
DSOs	Distribution system operators.
EH	Energy hub.
EMSs	Energy management systems.
EPRI	Electric Power Research Institute.
ESC	Energy sector coupling.
ESSs	Energy storage systems.
EV	Electric vehicle.
FACTS	Flexible AC transmission system.
FL	Feeder load.
GA	Genetic algorithm.
GWO	Gray Wolf Optimization.
HC	Hosting capacity.
HCC	HC coefficient.
ICA	Integrated Capacity Analysis.
IoT	Internet of Things.
LFC	Local frequency control.
LSA	Loss sensitivity analysis.
LV	Low voltage.
LVDSs	Low-voltage distribution systems.
MC	Monte Carlo.
MESs	Multi-carrier energy systems.
MILP	Mixed-integer linear programming.
ML	Machine learning.
MPPT	Maximum power point tracking.
MPS	Modern power system.
MRFO	Manta Ray Foraging optimization.
MV	Medium voltage.
NRR	Network reconfiguration and reinforcement.
OLTC	On-load tap changer.
OPF	Optimal power flow.
PCC	Point of common connection.
PDF	Probability distribution function.
PF	Power factor.
PIs	Performance indices.
PLL	Phase-locked loop.
PMF	Probability mass function.
PQ	Power quality.
PSO	Particle Swarm Optimization.
PV	Photovoltaics.
QSTS	Quasi-static time series.
RESs	Renewable energy sources.
RI	Risk index.
RL	Reinforcement Learning.
RPC	Reactive power control.
SCC	Short circuit capacity.
SG	Synchronous generator.
SVC	Static var compensator.
SVM	Support vector machine.
THD	Total harmonic distortion.
TR	Transformer rating.
UCP	Unit commitment problem.
UG	Utility grid.
VF	Voltage flicker.
VUF	Voltage unbalance factor.
WC	Worst-case.
WECS	Wind energy conversion system.
WT	Wind turbine.

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CREDIT AUTHOR STATEMENT

- Hossam H. H. Mousa: Conceptualization and Writing—Original Draft.
- Karar Mahmoud: Writing—Review and Editing and Supervision.
- Matti Lehtonen: Writing—Review and Editing and Supervision.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] H. H. H. Mousa, A.-R. Youssef, and E. E. M. Mohamed, "State of the art perturb and observe MPPT algorithms based wind energy conversion systems: A technology review," *Int. J. Electr. Power Energy Syst.*, vol. 126, Mar. 2021, Art. no. 106598. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0142061520318688

[2] (2000). *Global Direct Primary Energy Consumption*. Accessed: Jul. 5, 2023. [Online]. Available: https://ourworldindata.org/grapher/global-primary-energy?time=2000.latest

[3] (2000). *Electricity Production By Source, World*. Accessed: Jul. 5, 2023. [Online]. Available: https://ourworldindata.org/grapher/electricity-production-by-source?time=2000.latest

[4] *World Energy Consumption By Energy Source 2050 | Statista*. Accessed: Jul. 5, 2023. [Online]. Available: https://www.statista.com/statistics/222066/projected-global-energy-consumption-by-source/

[5] *Renewable Energy Capacity Worldwide By Country 2022 | Statista*. Accessed: Jul. 5, 2023. [Online]. Available: https://www.statista.com/statistics/267233/renewable-energy-capacity-worldwide-by-country/

[6] M. M. Haque and P. Wolfs, "A review of high PV penetrations in LV distribution networks: Present status, impacts and mitigation measures," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 1195–1208, Sep. 2016, doi: 10.1016/j.rser.2016.04.025.

[7] S. M. Ismael, S. H. E. A. Aleem, A. Y. Abdelaziz, and A. F. Zobaa, "State-of-the-art of hosting capacity in modern power systems with distributed generation," *Renew. Energy*, vol. 130, pp. 1002–1020, Jan. 2019.

[8] M. Bollen and M. Häger. (2005). *Power Quality: Interactions Between Distributed Energy Resources, the Grid, and Other Customers*. Leonardo Energy. Accessed: Nov. 6, 2022. [Online]. Available: http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-8584

[9] E. Mulenga, M. H. J. Bollen, and N. Etherden, "A review of hosting capacity quantification methods for photovoltaics in low-voltage distribution grids," *Int. J. Electr. Power Energy Syst.*, vol. 115, Feb. 2020, Art. no. 105445, doi: 10.1016/j.ijepes.2019.105445.

[10] M. T. Islam and M. J. Hossain, "Artificial intelligence for hosting capacity analysis: A systematic literature review," *Energies*, vol. 16, no. 4, p. 1864, Feb. 2023, doi: 10.3390/en16041864.

[11] N. Qamar, A. Arshad, K. Mahmoud, and M. Lehtonen, "Hosting capacity in distribution grids: A review of definitions, performance indices, determination methodologies, and enhancement techniques," *Energy Sci. Eng.*, vol. 11, no. 4, pp. 1536–1559, Apr. 2023, doi: 10.1002/ese3.1389.

[12] M. Zain ul Abideen, O. Ellabban, and L. Al-Fagih, "A review of the tools and methods for distribution networks' hosting capacity calculation," *Energies*, vol. 13, no. 11, p. 2758, Jun. 2020, doi: 10.3390/en13112758.

[13] J. Suchithra, D. Robinson, and A. Rajabi, "Hosting capacity assessment strategies and reinforcement learning methods for coordinated voltage control in electricity distribution networks: A review," *Energies*, vol. 16, no. 5, p. 2371, Mar. 2023, doi: 10.3390/en16052371.

[14] A. A. Eladl, M. I. El-Afifi, M. M. El-Saadawi, and B. E. Sedhom, "A review on energy hubs: Models, methods, classification, applications, and future trends," *Alexandria Eng. J.*, vol. 68, pp. 315–342, Apr. 2023, doi: 10.1016/j.aej.2023.01.021.

[15] S. Karagiannopoulos, P. Aristidou, and G. Hug, "Data-driven local control design for active distribution grids using off-line optimal power flow and machine learning techniques," *IEEE Trans. Smart Grid*, vol. 10, no. 6, pp. 6461–6471, Nov. 2019, doi: 10.1109/TSG.2019.2905348.

[16] S. Mahdi Noori R. A., P. Scott, M. Mahmoodi, and A. Attarha, "Data-driven adjustable robust solution to voltage-regulation problem in PV-rich distribution systems," *Int. J. Electr. Power Energy Syst.*, vol. 141, Oct. 2022, Art. no. 108118, doi: 10.1016/j.ijepes.2022.108118.

[17] N. J. van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, Dec. 2009, doi: 10.1007/s11192-009-0146-3.

[18] S. Fatima, V. Püvi, and M. Lehtonen, "Review on the PV hosting capacity in distribution networks," *Energies*, vol. 13, no. 18, p. 4756, Sep. 2020, doi: 10.3390/en13184756.

[19] F. Ding and B. Mather, "On distributed PV hosting capacity estimation, sensitivity study, and improvement," *IEEE Trans. Sustain. Energy*, vol. 8, no. 3, pp. 1010–1020, Jul. 2017, doi: 10.1109/TSTE.2016.2640239.

[20] C. T. Gaunt, E. Namanya, and R. Herman, "Voltage modelling of LV feeders with dispersed generation: Limits of penetration of randomly connected photovoltaic generation," *Electr. Power Syst. Res.*, vol. 143, pp. 1–6, Feb. 2017, doi: 10.1016/j.epsr.2016.08.042.

[21] H. Yao, W. Qin, X. Jing, Z. Zhu, K. Wang, X. Han, and P. Wang, "Possibilistic evaluation of photovoltaic hosting capacity on distribution networks under uncertain environment," *Appl. Energy*, vol. 324, Oct. 2022, Art. no. 119681, doi: 10.1016/j.apenergy.2022.119681.

[22] R. Torquato, D. Salles, C. Oriente Pereira, P. C. M. Meira, and W. Freitas, "A comprehensive assessment of PV hosting capacity on low-voltage distribution systems," *IEEE Trans. Power Del.*, vol. 33, no. 2, pp. 1002–1012, Apr. 2018, doi: 10.1109/TPWRD.2018.2798707.

[23] A. Arshad, V. Püvi, and M. Lehtonen, "Monte Carlo-based comprehensive assessment of PV hosting capacity and energy storage impact in realistic Finnish low-voltage networks," *Energies*, vol. 11, no. 6, p. 1467, Jun. 2018, doi: 10.3390/en11061467.

[24] A. Arshad, M. Lindner, and M. Lehtonen, "An analysis of photo-voltaic hosting capacity in Finnish low voltage distribution networks," *Energies*, vol. 10, no. 11, p. 1702, Oct. 2017, doi: 10.3390/en10111702.

[25] M. M. Rahman, A. Arefi, G. M. Shafiullah, and S. Hettiwatte, "A new approach to voltage management in unbalanced low voltage networks using demand response and OLTC considering consumer preference," *Int. J. Electr. Power Energy Syst.*, vol. 99, pp. 11–27, Jul. 2018, doi: 10.1016/j.ijepes.2017.12.034.

[26] C. Long and L. F. Ochoa, "Voltage control of PV-rich LV networks: OLTC-fitted transformer and capacitor banks," *IEEE Trans. Power Syst.*, vol. 31, no. 5, pp. 4016–4025, Sep. 2016, doi: 10.1109/TPWRS.2015.2494627.

[27] A. T. Procopiou and L. F. Ochoa, "Voltage control in PV-rich LV networks without remote monitoring," *IEEE Trans. Power Syst.*, vol. 32, no. 2, pp. 1224–1236, Mar. 2017, doi: 10.1109/TPWRS.2016.2591063.

[28] C. Heinrich, P. Fortenbacher, A. Fuchs, and G. Andersson, "PV-integration strategies for low voltage networks," in *Proc. IEEE Int. Energy Conf. (ENERGYCON)*, Apr. 2016, pp. 1–6, doi: 10.1109/ENERGYCON.2016.7514141.

[29] R. Yan and T. K. Saha, "Investigation of voltage stability for residential customers due to high photovoltaic penetrations," *IEEE Trans. Power Syst.*, vol. 27, no. 2, pp. 651–662, May 2012, doi: 10.1109/TPWRS.2011.2180741.

[30] P. Hasanpor Divshali and L. Söder, "Improving hosting capacity of rooftop PVs by quadratic control of an LV-central BSS," *IEEE Trans. Smart Grid*, vol. 10, no. 1, pp. 919–927, Jan. 2019, doi: 10.1109/TSG.2017.2754943.

[31] S. M. Mohseni-Bonab, A. Rabiee, and B. Mohammadi-Ivatloo, "Voltage stability constrained multi-objective optimal reactive power dispatch under load and wind power uncertainties: A stochastic approach," *Renew. Energy*, vol. 85, pp. 598–609, Jan. 2016, doi: 10.1016/j.renene.2015.07.021.

[32] M. Di Somma, L. Ciabattoni, G. Comodi, and G. Graditi, "Managing plug-in electric vehicles in eco-environmental operation optimization of local multi-energy systems," *Sustain. Energy, Grids Netw.*, vol. 23, Sep. 2020, Art. no. 100376, doi: 10.1016/j.segan.2020.100376.

[33] Å. L. Sørensen, K. B. Lindberg, I. Sartori, and I. Andresen, "Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data," *Energy Buildings*, vol. 241, Jun. 2021, Art. no. 110923, doi: 10.1016/j.enbuild.2021.110923.

[34] M. Askeland, S. Backe, S. Bjarghov, K. B. Lindberg, and M. Korpås, "Activating the potential of decentralized flexibility and energy resources to increase the EV hosting capacity: A case study of a multi-stakeholder local electricity system in Norway," *Smart Energy*, vol. 3, Aug. 2021, Art. no. 100034, doi: 10.1016/j.segy.2021.100034.

[35] A. Maulik, "Probabilistic power management of a grid-connected microgrid considering electric vehicles, demand response, smart transformers, and soft open points," *Sustain. Energy, Grids Netw.*, vol. 30, Jun. 2022, Art. no. 100636, doi: 10.1016/j.segan.2022.100636.

[36] M. K. Hasan, A. A. Habib, S. Islam, M. Balfaqih, K. M. Alfawaz, and D. Singh, "Smart grid communication networks for electric vehicles empowering distributed energy generation: Constraints, challenges, and recommendations," *Energies*, vol. 16, no. 3, p. 1140, Jan. 2023, doi: 10.3390/en16031140.

[37] A. Shukla, S. Dutta, S. K. Sahu, and P. K. Sadhu, "A narrative perspective of island detection methods under the lens of cyber-attack in data-driven smart grid," *J. Electr. Syst. Inf. Technol.*, vol. 10, no. 1, pp. 1–32, Mar. 2023, doi: 10.1186/s43067-023-00083-4.

[38] L. A. Wong, V. K. Ramachandaramurthy, P. Taylor, J. B. Ekanayake, S. L. Walker, and S. Padmanaban, "Review on the optimal placement, sizing and control of an energy storage system in the distribution network," *J. Energy Storage*, vol. 21, pp. 489–504, Feb. 2019, doi: 10.1016/j.est.2018.12.015.

[39] L. F. Henrique, W. N. Silva, C. C. A. Silva, B. H. Dias, L. W. Oliveira, and M. C. D. Almeida, "Optimal siting and sizing of distributed energy resources in a smart campus," *Electr. Power Syst. Res.*, vol. 217, Apr. 2023, Art. no. 109095, doi: 10.1016/j.epsr.2022.109095.

[40] A. Koirala, T. Van Acker, R. D'hulst, and D. Van Hertem, "Hosting capacity of photovoltaic systems in low voltage distribution systems: A benchmark of deterministic and stochastic approaches," *Renew. Sustain. Energy Rev.*, vol. 155, Mar. 2022, Art. no. 111899, doi: 10.1016/j.rser.2021.111899.

[41] J. Deuse, D. Benintendi, P. J. Agrell, and P. Bogetoft, "Power system and market integration of DER, the EU-DEEP approach," in *Proc. 18th Int. Conf. Exhib. Electr. Distrib. (CIRED)*, 2005, pp. 175–178, doi: 10.1049/cp:20051414.

[42] M. H. J. Bollen, F. Sollerkvist, E. O. A. Larsson, and C. M. Lundmark, "Limits to the hosting capacity of the grid for equipment emitting high-frequency distortion," in *Proc. Nordic Distrib. Asset Manag. Conf.*, 2006, pp. 1–6.

[43] M. H. J. Bollen and F. Hassan, *Integration of Distributed Generation in the Power System*, vol. 80. Hoboken, NJ, USA: Wiley, 2011.

[44] T. Walla. *Hosting Capacity for Photovoltaics in Swedish Distribution Grids*. Accessed: Nov. 6, 2022. [Online]. Available: http://www.teknat.uu.se/student

[45] *Capacity of Distribution Feeders for Hosting DER Working Group C6.24*, 2014. [Online]. Available: https://www.e-cigre.org/publications/detail/elt-275-7-capacity-of-distribution-feeders-for-hosting-der.html

[46] N. Etherden, "Increasing the hosting capacity of distributed energy resources using storage and communication," Diss. Luleå tekniska universitet, 2014.

[47] W. Sun. (Jun. 2015). *Maximising Renewable Hosting Capacity in Electricity Networks*. Accessed: Nov. 7, 2022. [Online]. Available: https://era.ed.ac.uk/handle/1842/10483

[48] F. Alalamat. *Increasing the Hosting Capacity of Radial Distribution Grids in Jordan*. Accessed: Nov. 7, 2022. [Online]. Available: http://awww.teknat.uu.se/student

[49] N. Etherden, S. Ab, M. Bollen, S. Ackeby, and O. Lennerhag, "The transparant hosting-capacity approach—Overview, applications and developments," in *Proc. Int. Conf. Exhib. Electr. Distrib.*, Jun. 2015.

[50] H. Al-Saadi, R. Zivanovic, and S. F. Al-Sarawi, "Probabilistic hosting capacity for active distribution networks," *IEEE Trans. Ind. Informat.*, vol. 13, no. 5, pp. 2519–2532, Oct. 2017, doi: 10.1109/TII.2017.2698505.

[51] S. Breker, J. Rentmeister, B. Sick, and M. Braun, "Hosting capacity of low-voltage grids for distributed generation: Classification by means of machine learning techniques," *Appl. Soft Comput.*, vol. 70, pp. 195–207, Sep. 2018, doi: 10.1016/j.asoc.2018.05.007.

[52] S.-E. Razavi, E. Rahimi, M. S. Javadi, A. E. Nezhad, M. Lotfi, M. Shafie-khah, and J. P. S. Catalão, "Impact of distributed generation on protection and voltage regulation of distribution systems: A review," *Renew. Sustain. Energy Rev.*, vol. 105, pp. 157–167, May 2019, doi: 10.1016/j.rser.2019.01.050.

[53] I. Oladeji, P. Makolo, M. Abdillah, J. Shi, and R. Zamora, "Security impacts assessment of active distribution network on the modern grid operation—A review," *Electronics*, vol. 10, no. 16, p. 2040, Aug. 2021, doi: 10.3390/electronics10162040.

[54] Y. Zhang, X. Shi, H. Zhang, Y. Cao, and V. Terzija, "Review on deep learning applications in frequency analysis and control of modern power system," *Int. J. Electr. Power Energy Syst.*, vol. 136, Mar. 2022, Art. no. 107744, doi: 10.1016/j.ijepes.2021.107744.

[55] A. Eslami, M. Negnevitsky, E. Franklin, and S. Lyden, "Review of AI applications in harmonic analysis in power systems," *Renew. Sustain. Energy Rev.*, vol. 154, Feb. 2022, Art. no. 111897, doi: 10.1016/j.rser.2021.111897.

[56] A. Rajabi, S. Elphick, J. David, A. Pors, and D. Robinson, "Innovative approaches for assessing and enhancing the hosting capacity of PV-rich distribution networks: An Australian perspective," *Renew. Sustain. Energy Rev.*, vol. 161, Jun. 2022, Art. no. 112365, doi: 10.1016/j.rser.2022.112365.

[57] V. Umoh, I. Davidson, A. Adebiyi, and U. Ekpe, "Methods and tools for PV and EV hosting capacity determination in low voltage distribution networks—A review," *Energies*, vol. 16, no. 8, p. 3609, Apr. 2023, doi: 10.3390/en16083609.

[58] F. M. AlAlamat, "Increasing the hosting capacity of radial distribution grids in Jordan," Ph.D. dissertation, Uppsala Univ., Uppsala, Sweden, 2015.

[59] J. Hu, M. Marinelli, M. Coppo, A. Zecchino, and H. W. Bindner, "Coordinated voltage control of a decoupled three-phase on-load tap changer transformer and photovoltaic inverters for managing unbalanced networks," *Electr. Power Syst. Res.*, vol. 131, pp. 264–274, Feb. 2016, doi: 10.1016/j.epsr.2015.10.025.

[60] E. De Jaeger, A. D. Bois, and B. Martin, "Hosting capacity of LV distribution grids for small distributed generation units, referring to voltage level and unbalance," in *Proc. 22nd Int. Conf. Exhib. Electr.Distrib. (CIRED)*, Jun. 2013, pp. 1–4, doi: 10.1049/cp.2013.1171.

[61] B. Wang, C. Zhang, Z. Y. Dong, and X. Li, "Improving hosting capacity of unbalanced distribution networks via robust allocation of battery energy storage systems," *IEEE Trans. Power Syst.*, vol. 36, no. 3, pp. 2174–2185, May 2021, doi: 10.1109/TPWRS.2020.3029532.

[62] J. Barros, M. de Apráiz, and R. I. Diego, "A review of international limits for rapid voltage changes in public distribution networks," *Renew. Sustain. Energy Rev.*, vol. 144, Jul. 2021, Art. no. 110966, doi: 10.1016/j.rser.2021.110966.

[63] A. Arshad and M. Lehtonen, "A comprehensive voltage control strategy with voltage flicker compensation for highly PV penetrated distribution networks," *Electr. Power Syst. Res.*, vol. 172, pp. 105–113, Jul. 2019, doi: 10.1016/j.epsr.2019.02.019.

[64] K. Mahmoud and M. Lehtonen, "Three-level control strategy for minimizing voltage deviation and flicker in PV-rich distribution systems," *Int. J. Electr. Power Energy Syst.*, vol. 120, Sep. 2020, Art. no. 105997, doi: 10.1016/j.ijepes.2020.105997.

[65] F. Ferdowsi, S. Mehraeen, and G. B. Upton, "Assessing distribution network sensitivity to voltage rise and flicker under high penetration of behind-the-meter solar," *Renew. Energy*, vol. 152, pp. 1227–1240, Jun. 2020, doi: 10.1016/j.renene.2019.12.124.

[66] Y. Gui et al., "Voltage support with PV inverters in low-voltage distribution networks: An overview," *IEEE J. Emerg. Sel. Topics Power Electron.*, early access, 2023. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/10138382, doi: 10.1109/jestpe.2023.3280926.

[67] A. Mishra and K. Chatterjee, "Flicker attenuation using FACTS device for DFIG-based WECS connected to distribution network," *IEEE Syst. J.*, vol. 17, no. 1, pp. 282–293, Mar. 2023, doi: 10.1109/JSYST.2022.3161469.

[68] K. Rafał, J. Biskupski, S. Bykuć, and P. Chaja, "Dynamic voltage regulation and unbalance compensation in a low-voltage distribution network using energy storage system," *Appl. Sci.*, vol. 12, no. 22, p. 11678, Nov. 2022, doi: 10.3390/app122211678.

[69] A. Ghaffari, A. Askarzadeh, and R. Fadaeinedjad, "Optimal allocation of energy storage systems, wind turbines and photovoltaic systems in distribution network considering flicker mitigation," *Appl. Energy*, vol. 319, Aug. 2022, Art. no. 119253, doi: 10.1016/j.apenergy.2022.119253.

[70] S. M. Alshareef, "Analyzing and mitigating the impacts of integrating fast-charging stations on the power quality in electric power distribution systems," *Sustainability*, vol. 14, no. 9, p. 5595, May 2022, doi: 10.3390/su14095595.

[71] M. Čerňan, Z. Müller, J. Tlustý, and V. Valouch, "An improved SVC control for electric arc furnace voltage flicker mitigation," *Int. J. Electr. Power Energy Syst.*, vol. 129, Jul. 2021, Art. no. 106831, doi: 10.1016/j.ijepes.2021.106831.

[72] R. A. Shayani and M. A. G. de Oliveira, "Photovoltaic generation penetration limits in radial distribution systems," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1625–1631, Aug. 2011, doi: 10.1109/TPWRS.2010.2077656.

[73] M. R. Khalid, M. S. Alam, A. Sarwar, and M. S. J. Asghar, "A comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid," *eTransportation*, vol. 1, Aug. 2019, Art. no. 100006, doi: 10.1016/j.etran.2019.100006.

[74] S. S. Letha, M. H. J. Bollen, T. Busatto, A. E. Delgado, E. Mulenga, H. Bakhtiari, J. Sutaria, K. M. U. Ahmed, N. Nakhodchi, S. Sakar, and V. Ravindran, "Power quality issues of electro-mobility on distribution network—An overview," *Energies*, vol. 16, no. 13, p. 4850, Jun. 2023, doi: 10.3390/en16134850.

[75] K. Prakash, M. Ali, M. N. I. Siddique, A. K. Karmaker, C. A. Macana, D. Dong, and H. R. Pota, "Bi-level planning and scheduling of electric vehicle charging stations for peak shaving and congestion management in low voltage distribution networks," *Comput. Electr. Eng.*, vol. 102, Sep. 2022, Art. no. 108235, doi: 10.1016/j.compeleceng.2022.108235.

[76] P. Pradhan, I. Ahmad, D. Habibi, G. Kothapalli, and M. A. S. Masoum, "Reducing the impacts of electric vehicle charging on power distribution transformers," *IEEE Access*, vol. 8, pp. 210183–210193, 2020, doi: 10.1109/ACCESS.2020.3040056.

[77] I. Daminov, A. Prokhorov, R. Caire, and M.-C. Alvarez-Herault, "Assessment of dynamic transformer rating, considering current and temperature limitations," *Int. J. Electr. Power Energy Syst.*, vol. 129, Jul. 2021, Art. no. 106886, doi: 10.1016/j.ijepes.2021.106886.

[78] E. Mulenga, M. H. J. Bollen, and N. Etherden, "Limits set by component loadability on solar power integration in distribution networks," *Electr. Power Syst. Res.*, vol. 209, Aug. 2022, Art. no. 107951, doi: 10.1016/j.epsr.2022.107951.

[79] R. O. Oliyide and L. M. Cipcigan, "Adaptive thermal model for loading of transformers in low carbon electricity distribution networks," *Sci. Afr.*, vol. 20, Jul. 2023, Art. no. e01683, doi: 10.1016/j.sciaf.2023.e01683.

[80] S. Fatima, V. Püvi, A. Arshad, M. Pourakbari-Kasmaei, and M. Lehtonen, "Comparison of economical and technical photovoltaic hosting capacity limits in distribution networks," *Energies*, vol. 14, no. 9, p. 2405, Apr. 2021, doi: 10.3390/en14092405.

[81] M. A. Akbari, J. Aghaei, M. Barani, M. Savaghebi, M. Shafie-Khah, J. M. Guerrero, and J. P. S. Catalão, "New metrics for evaluating technical benefits and risks of DGs increasing penetration," *IEEE Trans. Smart Grid*, vol. 8, no. 6, pp. 2890–2902, Nov. 2017, doi: 10.1109/TSG.2017.2665530.

[82] H. Sadeghian and Z. Wang, "A novel impact-assessment framework for distributed PV installations in low-voltage secondary networks," *Renew. Energy*, vol. 147, pp. 2179–2194, Mar. 2020, doi: 10.1016/j.renene.2019.09.117.

[83] S. Lakshmi and S. Ganguly, "Simultaneous optimisation of photovoltaic hosting capacity and energy loss of radial distribution networks with open unified power quality conditioner allocation," *IET Renew. Power Gener.*, vol. 12, no. 12, pp. 1382–1389, Sep. 2018, doi: 10.1049/iet-rpg.2018.5389.

[84] W. Haider, S. J. U. Hassan, A. Mehdi, A. Hussain, G. O. M. Adjayeng, and C.-H. Kim, "Voltage profile enhancement and loss minimization using optimal placement and sizing of distributed generation in reconfigured network," *Machines*, vol. 9, no. 1, p. 20, Jan. 2021, doi: 10.3390/machines9010020.

[85] I. Oladeji, R. Zamora, and T. T. Lie, "Security constrained optimal placement of renewable energy sources distributed generation for modern grid operations," *Sustain. Energy, Grids Netw.*, vol. 32, Dec. 2022, Art. no. 100897, doi: 10.1016/j.segan.2022.100897.

[86] A. Soroudi, A. Rabiee, and A. Keane, "Distribution networks' energy losses versus hosting capacity of wind power in the presence of demand flexibility," *Renew. Energy*, vol. 102, pp. 316–325, Mar. 2017, doi: 10.1016/j.renene.2016.10.051.

[87] I. Diahovchenko and L. Petrichenko, "Assessment of energy losses in power distribution systems with individual prosumers and energy communities," *J. Eng.*, vol. 2023, no. 3, Mar. 2023, Art. no. e12243, doi: 10.1049/tje2.12243.

[88] K. Gholami, M. R. Islam, M. M. Rahman, A. Azizivahed, and A. Fekih, "State-of-the-art technologies for volt-var control to support the penetration of renewable energy into the smart distribution grids," *Energy Rep.*, vol. 8, pp. 8630–8651, Nov. 2022, doi: 10.1016/j.egyr.2022.06.080.

[89] I. N. Santos, V. Ćuk, P. M. Almeida, M. H. J. Bollen, and P. F. Ribeiro, "Considerations on hosting capacity for harmonic distortions on transmission and distribution systems," *Electr. Power Syst. Res.*, vol. 119, pp. 199–206, Feb. 2015, doi: 10.1016/j.epsr.2014.09.020.

[90] S. Sakar, M. E. Balci, S. H. E. Abdel Aleem, and A. F. Zobaa, "Integration of large- scale PV plants in non-sinusoidal environments: Considerations on hosting capacity and harmonic distortion limits," *Renew. Sustain. Energy Rev.*, vol. 82, pp. 176–186, Feb. 2018, doi: 10.1016/j.rser.2017.09.028.

[91] S. Wang, X. Liu, K. Wang, L. Wu, and Y. Zhang, "Tracing harmonic contributions of multiple distributed generations in distribution systems with uncertainty," *Int. J. Electr. Power Energy Syst.*, vol. 95, pp. 585–591, Feb. 2018, doi: 10.1016/j.ijepes.2017.09.014.

[92] W. Sun and G. P. Harrison, "Distribution network hosting capacity assessment: Incorporating probabilistic harmonic distortion limits using chance constrained optimal power flow," *IET Smart Grid*, vol. 5, no. 2, pp. 63–75, Apr. 2022, doi: 10.1049/stg2.12052.

[93] T. D. Pham, "Integration of photovoltaic units, wind turbine units, battery energy storage system, and capacitor bank in the distribution system for minimizing total costs considering harmonic distortions," *Iran. J. Sci. Technol.-Trans. Electr. Eng.*, vol. 2023, pp. 1–18, May 2023, doi: 10.1007/S40998-023-00613-W.

[94] B. Basta and W. G. Morsi, "Low and high order harmonic distortion in the presence of fast charging stations," *Int. J. Electr. Power Energy Syst.*, vol. 126, Mar. 2021, Art. no. 106557, doi: 10.1016/j.ijepes.2020.106557.

[95] N. Nakhodchi and M. H. J. Bollen, "Impact of modelling of MV network and remote loads on estimated harmonic hosting capacity for an EV fast charging station," *Int. J. Electr. Power Energy Syst.*, vol. 147, May 2023, Art. no. 108847, doi: 10.1016/j.ijepes.2022.108847.

[96] B. E. Carmelito and J. M. D. C. Filho, "Hosting capacity of electric vehicles on LV/MV distribution Grids—A new methodology assessment," *Energies*, vol. 16, no. 3, p. 1509, Feb. 2023, doi: 10.3390/en16031509.

[97] S. H. E. Abdel Aleem, A. F. Zobaa, M. E. Balci, and S. M. Ismael, "Harmonic overloading minimization of frequency-dependent components in harmonics polluted distribution systems using Harris hawks optimization algorithm," *IEEE Access*, vol. 7, pp. 100824–100837, 2019, doi: 10.1109/ACCESS.2019.2930831.

[98] E. Mengistu, B. Khan, Y. Qasaymeh, A. S. Alghamdi, M. Zubair, A. B. Awan, M. G. B. Ashiq, S. G. Ali, and C.M. Pérez-Oleaga, "Utilization of stockwell transform, support vector machine and D-STATCOM for the identification, classification and mitigation of power quality problems," *Sustainability*, vol. 15, no. 7, p. 6007, Mar. 2023, doi: 10.3390/su15076007.

[99] A. S. N. Huda and R. Živanović, "Large-scale integration of distributed generation into distribution networks: Study objectives, review of models and computational tools," *Renew. Sustain. Energy Rev.*, vol. 76, pp. 974–988, Sep. 2017, doi: 10.1016/j.rser.2017.03.069.

[100] M. Rezkalla, M. Pertl, and M. Marinelli, "Electric power system inertia: Requirements, challenges and solutions," *Electr. Eng.*, vol. 100, no. 4, pp. 2677–2693, Dec. 2018, doi: 10.1007/S00202-018-0739-Z.

[101] P. Makolo, I. Oladeji, R. Zamora, and T.-T. Lie, "Data-driven inertia estimation based on frequency gradient for power systems with high penetration of renewable energy sources," *Electr. Power Syst. Res.*, vol. 195, Jun. 2021, Art. no. 107171, doi: 10.1016/j.epsr.2021.107171.

[102] . Yan and T. K. Saha, "A new tool to estimate maximum wind power penetration level: In perspective of frequency response adequacy," *Appl. Energy*, vol. 154, pp. 209–220, Sep. 2015, doi: 10.1016/j.apenergy.2015.04.085.

[103] D. Lekshmi J, Z. H. Rather, and B. C. Pal, "A new tool to assess maximum permissible solar PV penetration in a power system," *Energies*, vol. 14, no. 24, p. 8529, Dec. 2021, doi: 10.3390/en14248529.

[104] S. K. Jain, S. Bhongade, S. Agrawal, A. Mehbodniya, B. Sharma, S. Chowdhury, and J. L. Webber, "Interrelated solar and thermal plant autonomous generation control utilizing metaheuristic optimization," *Energies*, vol. 16, no. 8, p. 3355, Apr. 2023, doi: 10.3390/en16083355.

[105] A. Waheed Kumar, M. U. din Mufti, and M. Yaqoob Zargar, "Utilization of superconducting magnetic energy storage and doubly fed induction generator for enhancing stability of interconnected power system," *Int. J. Circuit Theory Appl.*, vol. 51, no. 11, pp. 5251–5268, Nov. 2023, doi: 10.1002/cta.3699.

[106] K. Yan, G. Li, R. Zhang, Y. Xu, T. Jiang, and X. Li, "Frequency control and optimal operation of low-inertia power systems with HVDC and renewable energy: A review," *IEEE Trans. Power Syst.*, early access, Jun. 21, 2023, doi: 10.1109/TPWRS.2023.3288086.

[107] F. Shahnazian, J. Adabi, and E. Pouresmaeil, "Frequency stability improvements based on automatic adjustment of synchronous power controller parameters," *Electr. Eng.*, vol. 104, no. 5, pp. 3453–3463, Oct. 2022, doi: 10.1007/S00202-022-01558-9.

[108] T. Sato, F. Alsharif, A. Umemura, R. Takahashi, and J. Tamura, "Stability improvement of power system by cooperative virtual inertia control and reactive power control of PMSG wind generator and battery," *Electr. Eng. Jpn.*, vol. 215, no. 1, Mar. 2022, Art. no. e23362, doi: 10.1002/eej.23362.

[109] A. M. M. Nour, A. Y. Hatata, A. A. Helal, and M. M. El-Saadawi, "Review on voltage-violation mitigation techniques of distribution networks with distributed rooftop PV systems," *IET Gener., Transmiss. Distrib.*, vol. 14, no. 3, pp. 349–361, Feb. 2020, doi: 10.1049/iet-gtd.2019.0851.

[110] W. K. Yap, L. Havas, E. Overend, and V. Karri, "Neural network-based active power curtailment for overvoltage prevention in low voltage feeders," *Expert Syst. Appl.*, vol. 41, no. 4, pp. 1063–1070, Mar. 2014, doi: 10.1016/j.eswa.2013.07.103.

[111] W. Y. Atmaja, M. P. Lesnanto, and E. Y. Pramono, "Hosting capacity improvement using reactive power control strategy of rooftop PV inverters," in *Proc. IEEE 7th Int. Conf. Smart Energy Grid Eng. (SEGE)*, Aug. 2019, pp. 213–217, doi: 10.1109/SEGE.2019.8859888.

[112] M. Hanjalić, E. Melić, M. Šarić, and J. Hivziefendić, "Hosting capacity assessment in electrical power distribution systems using genetic algorithm," *Electric Power Compon. Syst.*, vol. 51, no. 19, pp. 2354–2366, Jul. 2023, doi: 10.1080/15325008.2023.2227180.

[113] J. Zhu, W. J. Nacmanson, L. F. Ochoa, and B. Hellyer, "Assessing the EV hosting capacity of Australian urban and rural MV–LV networks," *Electr. Power Syst. Res.*, vol. 212, Nov. 2022, Art. no. 108399, doi: 10.1016/j.epsr.2022.108399.

[114] S. Tunçel, M. Z. Oskouei, A. A. Şeker, T. Gözel, M. H. Hocaoğlu, M. Abapour, and B. Mohammadi-Ivatloo, "Risk assessment of renewable energy and multi-carrier energy storage integrated distribution systems," *Int. J. Energy Res.*, vol. 46, no. 15, pp. 23630–23642, Dec. 2022, doi: 10.1002/er.8661.

[115] J. Wang, W. Q. Wang, and H. Y. Wang, "Bi-stage operation optimization of active distribution networks with soft open point considering violation risk," *Energy Rep.*, vol. 8, pp. 14947–14961, Nov. 2022, doi: 10.1016/j.egyr.2022.11.093.

[116] D. Yao, Y. Lu, D. Zhang, S. Shi, M. Zhu, and B. Zhang, "PV hosting capacity evaluation method in distribution network considering overvoltage risk," *J. Phys., Conf. Ser.*, vol. 2351, no. 1, Oct. 2022, Art. no. 012032, doi: 10.1088/1742-6596/2351/1/012032.

[117] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, "Community energy storage for neutral voltage rise mitigation in four-wire multi-grounded LV feeders with unbalanced solar PV allocation," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2845–2855, Nov. 2015, doi: 10.1109/TSG.2015.2427872.

[118] K. Joshi and R. R. Gokaraju, "An iterative approach to improve PV hosting capacity for a remote community," in *Proc. IEEE Power Energy Soc. Gen. Meeting (PESGM)*, Aug. 2018, pp. 1–5, doi: 10.1109/PESGM.2018.8586196.

[119] Y.-J. Liu, Y.-H. Tai, C.-Y. Huang, H.-J. Su, P.-H. Lan, and M.-K. Hsieh, "Assessment of the PV hosting capacity for the medium-voltage 11.4 kV distribution feeder," in *Proc. IEEE Int. Conf. Appl. Syst. Invention (ICASI)*, Apr. 2018, pp. 381–384, doi: 10.1109/ICASI.2018.8394262.

[120] M. Patsalides, G. Makrides, A. Stavrou, V. Efthymiou, and G. E. Georghiou, "Assessing the photovoltaic (PV) hosting capacity of distribution grids," in *Proc. Medit. Conf. Power Gener., Transmiss., Distrib. Energy Convers. (MedPower)*, Nov. 2016, pp. 1–4, doi: 10.1049/cp.2016.1051.

[121] S. Hashemi, J. Østergaard, and G. Yang, "Effect of reactive power management of PV inverters on need for energy storage," in *Proc. IEEE 39th Photovoltaic Spec. Conf. (PVSC)*, Jun. 2013, pp. 2304–2308, doi: 10.1109/PVSC.2013.6744938.

[122] H. Abobakr, A. A. Z. Diab, Y. B. Hassan, and A. M. Ashraf, "Comparison of Egyptian standards for grid-connected photovoltaic power plants with IEC and IEEE standards: A case study in Egypt," *Int. J. Adv. Sci. Technol.*, vol. 28, no. 16, pp. 856–870, Dec. 2019. [Online]. Available: http://sersc.org/journals/index.php/IJAST/article/view/1964

[123] R. Cumpelík and P. Krejcí, "Undefined parameters and two-limit parameters in standard EN 50160 ED.3," in *Proc. 16th Int. Sci. Conf. Electr. Power Eng. (EPE)*, May 2015, pp. 433–436, doi: 10.1109/EPE.2015.7161205.

[124] T. Stetz, F. Marten, and M. Braun, "Improved low voltage grid-integration of photovoltaic systems in Germany," *IEEE Trans. Sustain. Energy*, vol. 4, no. 2, pp. 534–542, Apr. 2013, doi: 10.1109/TSTE.2012.2198925.

[125] A. Arshad and M. Lehtonen, "Instantaneous active/reactive power control strategy for flicker mitigation under high PV penetration," in *Proc. IEEE PES Innov. Smart Grid Technol. Conf. Eur. (ISGT-Europe)*, Oct. 2018, pp. 1–6, doi: 10.1109/ISGTEUROPE.2018.8571855.

[126] F. F. Rahman S., K. Adi W., Sarjiya, and L. M. Putranto, "Study on photovoltaic hosting in Yogyakarta electric distribution network," in *Proc. 5th Int. Conf. Inf. Technol., Comput., Electr. Eng. (ICITACEE)*, Sep. 2018, pp. 240–244, doi: 10.1109/ICITACEE.2018.8576961.

[127] D. Falabretti, M. Merlo, and M. Delfanti, "Network reconfiguration and storage systems for the hosting capacity improvement," in *Proc. 22nd Int. Conf. Exhib. Electr. Distrib. (CIRED)*, Jun. 2013, pp. 1–4, doi: 10.1049/cp.2013.1267.

[128] S. Kikuchi, M. Machida, J. Tamura, M. Imanaka, J. Baba, D. Iioka, K. Miura, M. Takagi, and H. Asano, "Hosting capacity analysis of many distributed photovoltaic systems in future distribution networks," in *Proc. IEEE Innov. Smart Grid Technol.-Asia (ISGT-Asia)*, Dec. 2017, pp. 1–5, doi: 10.1109/ISGT-Asia.2017.8378408.

[129] I. A. Essackjee and R. T. F. Ah King, "Maximum rooftop photovoltaic hosting capacity with harmonics as limiting factor—Case study for Mauritius," in *Proc. Int. Conf. Adv. Big Data, Comput. Data Commun.Syst. (icABCD)*, Aug. 2019, pp. 1–6, doi: 10.1109/ICABCD.2019.8851002.

[130] B. B. Navarro and M. M. Navarro, "A comprehensive solar PV hosting capacity in MV and LV radial distribution networks," in *Proc. IEEE PES Innov. Smart Grid Technol. Conf. Eur. (ISGT-Europe)*, Sep. 2017, pp. 1–6, doi: 10.1109/ISGTEUROPE.2017.8260210.

[131] N. K. Singh, M. Z. C. Wanik, A. A. Jabbar, and A. Sanfilippo, "Enhancing PV hosting capacity of a Qatar remote farm network using inverters ability to regulate reactive power—A case study," in *Proc. IEEE PES Innov. Smart Grid Technol. Eur. (ISGT-Europe)*, Sep. 2019, pp. 1–5, doi: 10.1109/ISGTEUROPE.2019.8905545.

[132] S. Pukhrem, M. Basu, M. F. Conlon, and K. Sunderland, "Enhanced network voltage management techniques under the proliferation of rooftop solar PV installation in low-voltage distribution network," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 5, no. 2, pp. 681–694, Jun. 2017, doi: 10.1109/JESTPE.2016.2614986.

[133] N. Etherden and M. H. J. Bollen, "Increasing the hosting capacity of distribution networks by curtailment of renewable energy resources," in *Proc. IEEE Trondheim PowerTech*, Jun. 2011, pp. 1–7, doi: 10.1109/PTC.2011.6019292.

[134] M. J. Weisshaupt, B. Schlatter, P. Korba, E. Kaffe, and F. Kienzle, "Evaluation of measures to operate urban low voltage grids considering future PV expansion," *IFAC-PapersOnLine*, vol. 49, no. 27, pp. 336–341, Jan. 2016, doi: 10.1016/j.ifacol.2016.10.714.

[135] P. B. Kitworawut, D. T. Azuatalam, O. C. Unigwe, and A. J. Collin, "An investigation into the technical impacts of microgeneration on UK-type LV distribution networks," in *Proc. IEEE Int. Conf. Renew. Energy Res. Appl. (ICRERA)*, Nov. 2016, pp. 124–129, doi: 10.1109/ICRERA.2016.7884478.

[136] F. Ding, K. Horowitz, B. Mather, and B. Palmintier, "Sequential mitigation solutions to enable distributed PV grid integration," in *Proc. IEEE Power Energy Soc. Gen. Meeting (PESGM)*, Aug. 2018, pp. 1–5, doi: 10.1109/PESGM.2018.8586525.

[137] H. V. Haghi, Z. Pecenak, J. Kleissl, J. Peppanen, M. Rylander, A. Renjit, and S. Coley, "Feeder impact assessment of smart inverter settings to support high PV penetration in California," in *Proc. IEEE Power Energy Soc. Gen. Meeting (PESGM)*, Aug. 2019, pp. 1–5, doi: 10.1109/PESGM40551.2019.8974016.

[138] T. P. Abud, A. A. Augusto, M. Z. Fortes, R. S. Maciel, and B. S. M. C. Borba, "State of the art Monte Carlo method applied to power system analysis with distributed generation," *Energies*, vol. 16, no. 1, p. 394, Dec. 2022, doi: 10.3390/en16010394.

[139] A. Ali, K. Mahmoud, D. Raisz, and M. Lehtonen, "Probabilistic approach for hosting high PV penetration in distribution systems via optimal oversized inverter with watt-var functions," *IEEE Syst. J.*, vol. 15, no. 1, pp. 684–693, Mar. 2021, doi: 10.1109/JSYST.2020.2982467.

[140] K. Mahmoud and M. Lehtonen, "Comprehensive analytical expressions for assessing and maximizing technical benefits of photovoltaics to distribution systems," *IEEE Trans. Smart Grid*, vol. 12, no. 6, pp. 4938–4949, Nov. 2021, doi: 10.1109/TSG.2021.3097508.

[141] H. H. H. Mousa, A. Ali, M. F. Shaaban, and M. A. Ismeil, "Optimal allocation of multiple capacitors in a hybrid AC/DC microgrid for power quality improvement," *Social Netw. Appl. Sci.*, vol. 5, no. 12, pp. 1–22, Nov. 2023, doi: 10.1007/s42452-023-05552-z.

[142] P.-C. Chen, R. Salcedo, Q. Zhu, F. de Leon, D. Czarkowski, Z.-P. Jiang, V. Spitsa, Z. Zabar, and R. E. Uosef, "Analysis of voltage profile problems due to the penetration of distributed generation in low-voltage secondary distribution networks," *IEEE Trans. Power Del.*, vol. 27, no. 4, pp. 2020–2028, Oct. 2012, doi: 10.1109/TPWRD.2012.2209684.

[143] D. Q. Hung, N. Mithulananthan, and K. Y. Lee, "Determining PV penetration for distribution systems with time-varying load models," *IEEE Trans. Power Syst.*, vol. 29, no. 6, pp. 3048–3057, Nov. 2014, doi: 10.1109/TPWRS.2014.2314133.

[144] S. Heslop, I. MacGill, and J. Fletcher, "Maximum PV generation estimation method for residential low voltage feeders," *Sustain. Energy, Grids Netw.*, vol. 7, pp. 58–69, Sep. 2016, doi: 10.1016/j.segan.2016.06.003.

[145] S. Fan, C. Li, Z. Wei, T. Pu, and X. Liu, "Method to determine the maximum generation capacity of distribution generation in low-voltage distribution feeders," *J. Eng.*, vol. 2017, no. 13, pp. 944–948, Jan. 2017, doi: 10.1049/joe.2017.0470.

[146] D. Schwanz, F. Möller, S. K. Rönnberg, J. Meyer, and M. H. J. Bollen, "Stochastic assessment of voltage unbalance due to single-phase-connected solar power," *IEEE Trans. Power Del.*, vol. 32, no. 2, pp. 852–861, Apr. 2017, doi: 10.1109/TPWRD.2016.2579680.

[147] R. Luthander, D. Lingfors, and J. Widén, "Large-scale integration of photovoltaic power in a distribution grid using power curtailment and energy storage," *Sol. Energy*, vol. 155, pp. 1319–1325, Oct. 2017, doi: 10.1016/j.solener.2017.07.083.

[148] T. Oliveira, P. Carvalho, P. Ribeiro, and B. Bonatto, "PV hosting capacity dependence on harmonic voltage distortion in low-voltage grids: Model validation with experimental data," *Energies*, vol. 11, no. 2, p. 465, Feb. 2018, doi: 10.3390/en11020465.

[149] M. D. Braga, S. D. Machado, I. C. Oliveira, T. E. C. de Oliveira, P. F. Ribeiro, and B. I. L. Lopes, "Harmonic hosting capacity approach in a radial distribution system due to PV integration using OpenDSS," in *Proc. 13th IEEE Int. Conf. Ind. Appl. (INDUSCON)*, Nov. 2018, pp. 222–228, doi: 10.1109/INDUSCON.2018.8627342.

[150] S. Rout and G. Biswal, "Hosting capacity assessment of electric vehicles integration in active distribution system," *J. Physics: Conf. Ser.*, vol. 1478, no. 1, Apr. 2020, Art. no. 012006, doi: 10.1088/1742-6596/1478/1/012006.

[151] S. S. Letha and M. Bollen, "Estimation of electric vehicle hosting capacity of a distribution network including ambient temperature," in *Proc. 26th Int. Conf. Exhib. Electr. Distrib. (CIRED)*, 2021, pp. 2350–2355, doi: 10.1049/ICP.2021.176610.1049/ICP.2021.1766.

[152] S. Munikoti, B. Natarajan, K. Jhala, and K. Lai, "Probabilistic voltage sensitivity analysis to quantify impact of high PV penetration on unbalanced distribution system," *IEEE Trans. Power Syst.*, vol. 36, no. 4, pp. 3080–3092, Jul. 2021, doi: 10.1109/TPWRS.2021.3053461.

[153] L. Zhao, C. Wan, P. Yu, M. Wu, and S. Zhao, "Assessment of distributed photovoltaic hosting capacity in integrated electricity and heat systems considering uncertainty," *IET Energy Syst. Integr.*, vol. 3, no. 3, pp. 317–326, Sep. 2021, doi: 10.1049/esi2.12029.

[154] S. J. U. Hassan, T. Gush, and C.-H. Kim, "Maximum hosting capacity assessment of distribution systems with multitype DERs using analytical OPF method," *IEEE Access*, vol. 10, pp. 100665–100674, 2022, doi: 10.1109/ACCESS.2022.3207488.

[155] J. Yuan, Y. Weng, and C.-W. Tan, "Determining maximum hosting capacity for PV systems in distribution grids," *Int. J. Electr. Power Energy Syst.*, vol. 135, Feb. 2022, Art. no. 107342, doi: 10.1016/j.ijepes.2021.107342.

[156] Z. A. Memon, D. M. Said, M. Y. Hassan, H. M. Munir, F. Alsaif, and S. Alsulamy, "Effective deterministic methodology for enhanced distribution network performance and plug-in electric vehicles," *Sustainability*, vol. 15, no. 9, p. 7078, Apr. 2023, doi: 10.3390/su15097078.

[157] A. K. Jain, K. Horowitz, F. Ding, N. Gensollen, B. Mather, and B. Palmintier, "Quasi-static time-series PV hosting capacity methodology and metrics," in *Proc. IEEE Power Energy Soc. Innov. Smart Grid Technol. Conf. (ISGT)*, Feb. 2019, pp. 1–5, doi: 10.1109/ISGT.2019.8791569.

[158] A. K. Jain, K. Horowitz, F. Ding, K. S. Sedzro, B. Palmintier, B. Mather, and H. Jain, "Dynamic hosting capacity analysis for distributed photovoltaic resources—Framework and case study," *Appl. Energy*, vol. 280, Dec. 2020, Art. no. 115633, doi: 10.1016/j.apenergy.2020.115633.

[159] X. Chen, W. Wu, and B. Zhang, "Robust capacity assessment of distributed generation in unbalanced distribution networks incorporating ANM techniques," *IEEE Trans. Sustain. Energy*, vol. 9, no. 2, pp. 651–663, Apr. 2018, doi: 10.1109/TSTE.2017.2754421.

[160] R. Lliuyacc-Blas and P. Kepplinger, "Violation-mitigation-based method for PV hosting capacity quantification in low voltage grids," *Int. J. Electr. Power Energy Syst.*, vol. 142, Nov. 2022, Art. no. 108318, doi: 10.1016/j.ijepes.2022.108318.

[161] K. Wang, S. Yang, X. Zhang, J. Cui, D. Zhang, and Y. Wei, "Evaluation method of distribution network carrying capacity based on Bayesian network," *J. Phys., Conf. Ser.*, vol. 2401, no. 1, Dec. 2022, Art. no. 012089, doi: 10.1088/1742-6596/2401/1/012089.

[162] A. Sahebi and S. Jadid, "A robust model of local energy market under a security constraint-based approach for distribution system operator and multi-energy microgrids," *Electr. Power Syst. Res.*, vol. 217, Apr. 2023, Art. no. 109164, doi: 10.1016/j.epsr.2023.109164.

[163] *Impact Factors, Methods, and Considerations for Calculating and Applying Hosting Capacity*. Accessed: Jul. 22, 2023. [Online]. Available: https://www.epri.com/research/products/000000003002011009

[164] M. Rylander, J. Smith, and W. Sunderman, "Streamlined method for determining distribution system hosting capacity," *IEEE Trans. Ind. Appl.*, vol. 52, no. 1, pp. 105–111, Jan. 2016, doi: 10.1109/TIA.2015.2472357.

[165] A. Arshad and M. Lehtonen, "A stochastic assessment of PV hosting capacity enhancement in distribution network utilizing voltage support techniques," *IEEE Access*, vol. 7, pp. 46461–46471, 2019, doi: 10.1109/ACCESS.2019.2908725.

[166] D. A. Quijano and A. Padilha-Feltrin, "Optimal integration of distributed generation and conservation voltage reduction in active distribution networks," *Int. J. Electr. Power Energy Syst.*, vol. 113, pp. 197–207, Dec. 2019, doi: 10.1016/j.ijepes.2019.05.039.

[167] D. Liu, C. Wang, F. Tang, and Y. Zhou, "Probabilistic assessment of hybrid wind-PV hosting capacity in distribution systems," *Sustainability*, vol. 12, no. 6, p. 2183, Mar. 2020, doi: 10.3390/su12062183.

[168] L. A. Gallego, J. F. Franco, and L. G. Cordero, "A fast-specialized point estimate method for the probabilistic optimal power flow in distribution systems with renewable distributed generation," *Int. J. Electr. Power Energy Syst.*, vol. 131, Oct. 2021, Art. no. 107049, doi: 10.1016/j.ijepes.2021.107049.

[169] E. Mulenga, M. H. J. Bollen, and N. Etherden, "Adapted stochastic PV hosting capacity approach for electric vehicle charging considering undervoltage," *Electricity*, vol. 2, no. 3, pp. 387–402, Sep. 2021, doi: 10.3390/electricity2030023.

[170] S. Munikoti, M. Abujubbeh, K. Jhala, and B. Natarajan, "A novel framework for hosting capacity analysis with spatio-temporal probabilistic voltage sensitivity analysis," *Int. J. Electr. Power Energy Syst.*, vol. 134, Jan. 2022, Art. no. 107426, doi: 10.1016/j.ijepes.2021.107426.

[171] C. D. Zuluaga-Ríos, A. Villa-Jaramillo, and S. D. Saldarriaga-Zuluaga, "Evaluation of distributed generation and electric vehicles hosting capacity in islanded DC grids considering EV uncertainty," *Energies*, vol. 15, no. 20, p. 7646, Oct. 2022, doi: 10.3390/en15207646.

[172] E. Mulenga, M. H. J. Bollen, and N. Etherden, "Solar PV stochastic hosting capacity in distribution networks considering aleatory and epistemic uncertainties," *Int. J. Electr. Power Energy Syst.*, vol. 130, Sep. 2021, Art. no. 106928, doi: 10.1016/j.ijepes.2021.106928.

[173] E. Mulenga, "Solar PV stochastic hosting capacity assessment considering epistemic (E) probability distribution function (PDF)," *Electricity*, vol. 3, no. 4, pp. 586–599, Dec. 2022, doi: 10.3390/electricity3040029.

[174] A. Koirala, M. U. Hashmi, R. D'Hulst, and D. Van Hertem, "Decoupled probabilistic feeder hosting capacity calculations using general polynomial chaos," *Electr. Power Syst. Res.*, vol. 211, Oct. 2022, Art. no. 108535, doi: 10.1016/j.epsr.2022.108535.

[175] T. P. Abud, E. Cataldo, R. S. Maciel, and B. S. M. C. Borba, "A modified bass model to calculate PVDG hosting capacity in LV networks," *Electr. Power Syst. Res.*, vol. 209, Aug. 2022, Art. no. 107966, doi: 10.1016/j.epsr.2022.107966.

[176] L. E. S. E Silva and J. P. A. Vieira, "Combined PV-PEV hosting capacity analysis in low-voltage distribution networks," *Electr. Power Syst. Res.*, vol. 206, May 2022, Art. no. 107829, doi: 10.1016/j.epsr.2022.107829.

[177] M. J. Chihota, B. Bekker, and T. Gaunt, "A stochastic analytic-probabilistic approach to distributed generation hosting capacity evaluation of active feeders," *Int. J. Electr. Power Energy Syst.*, vol. 136, Mar. 2022, Art. no. 107598, doi: 10.1016/j.ijepes.2021.107598.

[178] M. Seydali Seyf Abad, J. Ma, H. Marzooghi, and A. S. Ahmadyar, "Probabilistic impact assessment of residential BESSs on the HC of LV distribution systems," *Int. J. Electr. Power Energy Syst.*, vol. 136, Mar. 2022, Art. no. 107652, doi: 10.1016/j.ijepes.2021.107652.

[179] Y. Cho, E. Lee, K. Baek, and J. Kim, "Stochastic optimization-based hosting capacity estimation with volatile net load deviation in distribution grids," *Appl. Energy*, vol. 341, Jul. 2023, Art. no. 121075, doi: 10.1016/j.apenergy.2023.121075.

[180] *A Fast Quasi-Static Time Series (QSTS) Simulation Method for PV Impact Studies Using Voltage Sensitivities of Controllable Elements | IEEE Conference Publication | IEEE Xplore*. Accessed: Jul. 23, 2023. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/8366414

[181] A. Selim, M. Abdel-Akher, M. M. Aly, S. Kamel, and T. Senjyu, "Fast quasi-static time-series analysis and reactive power control of unbalanced distribution systems," *Int. Trans. Electr. Energy Syst.*, vol. 29, no. 1, p. e2673, Jan. 2019, doi: 10.1002/etep.2673.

[182] M. U. Qureshi, S. Grijalva, M. J. Reno, J. Deboever, X. Zhang, and R. J. Broderick, "A fast scalable quasi-static time series analysis method for PV impact studies using linear sensitivity model," *IEEE Trans. Sustain. Energy*, vol. 10, no. 1, pp. 301–310, Jan. 2019, doi: 10.1109/TSTE.2018.2833748.

[183] T. E. C. de Oliveira, M. Bollen, P. F. Ribeiro, P. M. S. de Carvalho, A. C. Zambroni, and B. D. Bonatto, "The concept of dynamic hosting capacity for distributed energy resources: Analytics and practical considerations," *Energies*, vol. 12, no. 13, p. 2576, Jul. 2019, doi: 10.3390/en12132576.

[184] M. Bartecka, G. Barchi, and J. Paska, "Time-series PV hosting capacity assessment with storage deployment," *Energies*, vol. 13, no. 10, p. 2524, May 2020, doi: 10.3390/en13102524.

[185] I. S. Lamprianidou, T. A. Papadopoulos, G. C. Kryonidis, E. F. Yetkin, K. D. Pippi, and A. I. Chrysochos, "Assessment of load and generation modelling on the quasi-static analysis of distribution networks," *Sustain. Energy, Grids Netw.*, vol. 27, Sep. 2021, Art. no. 100509, doi: 10.1016/j.segan.2021.100509.

[186] A. Parizad and C. Hatziadoniu, "Employing load and irradiance profiles for the allocation of PV arrays with inverter reactive power and battery storage in distribution networks—A fast comprehensive QSTS technique," *Int. J. Electr. Power Energy Syst.*, vol. 130, Sep. 2021, Art. no. 106915, doi: 10.1016/j.ijepes.2021.106915.

[187] L. F. Henrique, L. A. Bitencourt, B. S. M. C. Borba, and B. H. Dias, "Impacts of EV residential charging and charging stations on quasi-static time-series PV hosting capacity," *Electr. Eng.*, vol. 104, no. 4, pp. 2717–2728, Aug. 2022, doi: 10.1007/S00202-022-01513-8.

[188] S. Talkington, S. Grijalva, M. J. Reno, J. A. Azzolini, and D. Pinney, "A measurement-based approach to voltage-constrained hosting capacity analysis with controllable reactive power behind-the-meter," *Electr. Power Syst. Res.*, vol. 221, Aug. 2023, Art. no. 109395, doi: 10.1016/j.epsr.2023.109395.

[189] S. Fatima, V. Püvi, M. Pourakbari-Kasmaei, and M. Lehtonen, "Photovoltaic hosting capacity improvement based on the economic comparison between curtailment and network upgrade," *IET Gener., Transmiss. Distrib.*, vol. 17, no. 17, pp. 3848–3860, Jul. 2023, doi: 10.1049/gtd2.12936.

[190] J. A. Azzolini, M. J. Reno, N. S. Gurule, and K. A. W. Horowitz, "Evaluating distributed PV curtailment using quasi-static time-series simulations," *IEEE Open Access J. Power Energy*, vol. 8, pp. 365–376, 2021, doi: 10.1109/OAJPE.2021.3111821.

[191] W. K. Mashwani, R. Haider, and S. Brahim Belhaouari, "A multiswarm intelligence algorithm for expensive bound constrained optimization problems," *Complexity*, vol. 2021, pp. 1–18, Feb. 2021, doi: 10.1155/2021/5521951.

[192] K. Y. Gómez Díaz, S. E. De León Aldaco, J. Aguayo Alquicira, M. Ponce-Silva, and V. H. Olivares Peregrino, "Teaching–Learning-Based optimization algorithm applied in electronic engineering: A survey," *Electronics*, vol. 11, no. 21, p. 3451, Oct. 2022, doi: 10.3390/electronics11213451.

[193] M. Thirunavukkarasu, Y. Sawle, and H. Lala, "A comprehensive review on optimization of hybrid renewable energy systems using various optimization techniques," *Renew. Sustain. Energy Rev.*, vol. 176, Apr. 2023, Art. no. 113192, doi: 10.1016/j.rser.2023.113192.

[194] C. Edmunds, S. Galloway, J. Dixon, W. Bukhsh, and I. Elders, "Hosting capacity assessment of heat pumps and optimised electric vehicle charging on low voltage networks," *Appl. Energy*, vol. 298, Sep. 2021, Art. no. 117093, doi: 10.1016/j.apenergy.2021.117093.

[195] T. Gush, C.-H. Kim, S. Admasie, J.-S. Kim, and J.-S. Song, "Optimal smart inverter control for PV and BESS to improve PV hosting capacity of distribution networks using slime mould algorithm," *IEEE Access*, vol. 9, pp. 52164–52176, 2021, doi: 10.1109/ACCESS.2021.3070155.

[196] M. G. Hemeida, A. A. Ibrahim, A.-A.-A. Mohamed, S. Alkhalaf, and A. M. B. El-Dine, "Optimal allocation of distributed generators DG based Manta ray foraging optimization algorithm (MRFO)," *Ain Shams Eng. J.*, vol. 12, no. 1, pp. 609–619, Mar. 2021, doi: 10.1016/j.asej.2020.07.009.

[197] A. Ramadan, M. Ebeed, S. Kamel, E. M. Ahmed, and M. Tostado-Véliz, "Optimal allocation of renewable DGs using artificial hummingbird algorithm under uncertainty conditions," *Ain Shams Eng. J.*, vol. 14, no. 2, Mar. 2023, Art. no. 101872, doi: 10.1016/j.asej.2022.101872.

[198] L. D. L. Pereira, I. Yahyaoui, R. Fiorotti, L. S. de Menezes, J. F. Fardin, H. R. O. Rocha, and F. Tadeo, "Optimal allocation of distributed generation and capacitor banks using probabilistic generation models with correlations," *Appl. Energy*, vol. 307, Feb. 2022, Art. no. 118097, doi: 10.1016/j.apenergy.2021.118097.

[199] M. Purlu and B. E. Turkay, "Optimal allocation of renewable distributed generations using heuristic methods to minimize annual energy losses and voltage deviation index," *IEEE Access*, vol. 10, pp. 21455–21474, 2022, doi: 10.1109/ACCESS.2022.3153042.

[200] M. Z. U. Abideen, O. Ellabban, F. Ahmad, and L. Al-Fagih, "An enhanced approach for solar PV hosting capacity analysis in distribution networks," *IEEE Access*, vol. 10, pp. 120563–120577, 2022, doi: 10.1109/ACCESS.2022.3221944.

[201] T. Thanh Nguyen, T. Trung Nguyen, and B. Le, "Artificial ecosystem optimization for optimizing of position and operational power of battery energy storage system on the distribution network considering distributed generations," *Expert Syst. Appl.*, vol. 208, Dec. 2022, Art. no. 118127, doi: 10.1016/j.eswa.2022.118127.

[202] E. C. da Silva, O. D. Melgar-Dominguez, and R. Romero, "Simultaneous distributed generation and electric vehicles hosting capacity assessment in electric distribution systems," *IEEE Access*, vol. 9, pp. 110927–110939, 2021, doi: 10.1109/ACCESS.2021.3102684.

[203] B. Xu, G. Zhang, K. Li, B. Li, H. Chi, Y. Yao, and Z. Fan, "Reactive power optimization of a distribution network with high-penetration of wind and solar renewable energy and electric vehicles," *Protection Control Mod. Power Syst.*, vol. 7, no. 1, pp. 1–13, Dec. 2022, doi: 10.1186/S41601-022-00271-W.

[204] M. Elshahed, M. A. Tolba, A. M. El-Rifaie, A. Ginidi, A. Shaheen, and S. A. Mohamed, "An artificial rabbits' optimization to allocate PVSTATCOM for ancillary service provision in distribution systems," *Mathematics*, vol. 11, no. 2, p. 339, Jan. 2023, doi: 10.3390/math11020339.

[205] P. Pon Ragothama Priya, S. Baskar, S. Tamil Selvi, and C. K. Babulal, "Optimal allocation of hybrid renewable distributed generation with battery energy storage system using MOEA/D-DRA algorithm," *Int. Trans. Electr. Energy Syst.*, vol. 2023, pp. 1–18, May 2023, doi: 10.1155/2023/7316834.

[206] D. Mendoza Osorio and J. Rosero Garcia, "Optimization of distributed energy resources in distribution networks: Applications of convex optimal power flow formulations in distribution networks," *Int. Trans. Electr. Energy Syst.*, vol. 2023, pp. 1–16, Apr. 2023, doi: 10.1155/2023/1000512.

[207] M. Vellingiri, M. Rawa, S. Alghamdi, A. A. Alhussainy, Z. M. Ali, R. A. Turky, M. M. Refaat, and S. H. E. Abdel Aleem, "Maximum hosting capacity estimation for renewables in power grids considering energy storage and transmission lines expansion using hybrid sine cosine artificial rabbits algorithm," *Ain Shams Eng. J.*, vol. 14, no. 5, May 2023, Art. no. 102092, doi: 10.1016/j.asej.2022.102092.

[208] B. Ahmadi, O. Ceylan, and A. Ozdemir, "Reinforcement of the distribution grids to improve the hosting capacity of distributed generation: Multi-objective framework," *Electr. Power Syst. Res.*, vol. 217, Apr. 2023, Art. no. 109120, doi: 10.1016/j.epsr.2023.109120.

[209] S. Taheri, M. Jalali, V. Kekatos, and L. Tong, "Fast probabilistic hosting capacity analysis for active distribution systems," *IEEE Trans. Smart Grid*, vol. 12, no. 3, pp. 2000–2012, May 2021, doi: 10.1109/TSG.2020.3038651.

[210] E. J. Lima and L. C. G. Freitas, "Hosting capacity calculation deploying a hybrid methodology: A case study concerning the intermittent nature of photovoltaic distributed generation and the variable nature of energy consumption in a medium voltage distribution network," *Energies*, vol. 15, no. 3, p. 1223, Feb. 2022, doi: 10.3390/en15031223.

[211] C. Han, D. Lee, S. Song, and G. Jang, "Probabilistic assessment of PV hosting capacity under coordinated voltage regulation in unbalanced active distribution networks," *IEEE Access*, vol. 10, pp. 35578–35588, 2022, doi: 10.1109/ACCESS.2022.3163595.

[212] H. Wu, Y. Yuan, J. Zhu, and Y. Xu, "Assessment model for distributed wind generation hosting capacity considering complex spatial correlations," *J. Mod. Power Syst. Clean Energy*, vol. 10, no. 5, pp. 1194–1206, Sep. 2022, doi: 10.35833/MPCE.2020.000889.

[213] A. Jani, H. Karimi, and S. Jadid, "Two-layer stochastic day-ahead and real-time energy management of networked microgrids considering integration of renewable energy resources," *Appl. Energy*, vol. 323, Oct. 2022, Art. no. 119630, doi: 10.1016/j.apenergy.2022.119630.

[214] A.-N. Sharkawy, M. M. Ali, H. H. H. Mousa, A. S. Ali, G. T. Abdel-Jaber, H. S. Hussein, M. Farrag, and M.A. Ismeil, "Solar PV power estimation and upscaling forecast using different artificial neural networks types: Assessment, validation, and comparison," *IEEE Access*, vol. 11, pp. 19279–19300, 2023, doi: 10.1109/ACCESS.2023.3249108.

[215] M. Q. Raza and A. Khosravi, "A review on artificial intelligence based load demand forecasting techniques for smart grid and buildings," *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1352–1372, Oct. 2015, doi: 10.1016/j.rser.2015.04.065.

[216] A. T. Procopiou, M. Z. Liu, L. F. Ochoa, T. Langstaff, and J. Harding, "Smart meter-driven estimation of PV hosting capacity," *CIRED-Open Access Proc. J.*, vol. 2020, no. 1, pp. 128–131, Jan. 2020, doi: 10.1049/oap-cired.2021.0287.

[217] K. Nweye and Z. Nagy, "MartinI: Smart meter driven estimation of HVAC schedules and energy savings based on Wi-Fi sensing and clustering," *Appl. Energy*, vol. 316, Jun. 2022, Art. no. 118980, doi: 10.1016/j.apenergy.2022.118980.

[218] T. Matijašević, T. Antić, and T. Capuder, "A systematic review of machine learning applications in the operation of smart distribution systems," *Energy Rep.*, vol. 8, pp. 12379–12407, Nov. 2022, doi: 10.1016/j.egyr.2022.09.068.

[219] V. Bassi, L. Ochoa, and T. Alpcan, "Model-free voltage calculations for PV-rich LV networks: Smart meter data and deep neural networks," in *Proc. IEEE Madrid PowerTech*, Jun. 2021, pp. 1–6, doi: 10.1109/PowerTech46648.2021.9494847.

[220] X. Pan, K. Liu, J. Wang, Y. Hu, and J. Zhao, "Capacity allocation method based on historical data-driven search algorithm for integrated PV and energy storage charging station," *Sustainability*, vol. 15, no. 6, p. 5480, Mar. 2023, doi: 10.3390/su15065480.

[221] N. Stringer, N. Haghdadi, A. Bruce, and I. MacGill, "Fair consumer outcomes in the balance: Data driven analysis of distributed PV curtailment," *Renew. Energy*, vol. 173, pp. 972–986, Aug. 2021, doi: 10.1016/j.renene.2021.04.020.

[222] J. Wu, J. Yuan, Y. Weng, and R. Ayyanar, "Spatial-temporal deep learning for hosting capacity analysis in distribution grids," *IEEE Trans. Smart Grid*, vol. 14, no. 1, pp. 354–364, Jan. 2023, doi: 10.1109/TSG.2022.3196943.

[223] S. Kirubakaran, V. Nagarajan, S. C. K. Dhayapulley, I. D. Soubache, S. R. Pasupuleti, A. Kumar, R. Rastogi, and S. Vasudevan, "Hybrid deep learning-based grid-supportive renewable energy systems for maximizing power generation using optimum sizing," *Electric Power Compon. Syst.*, vol. 51, no. 15, pp. 1597–1611, Sep. 2023, doi: 10.1080/15325008.2023.2201249.

[224] W. Wang, J. Keen, J. Bank, J. Giraldez, and K. Montano-Martinez, "An automated approach for screening residential PV applications using a random forest model," *IEEE Open Access J. Power Energy*, vol. 10, pp. 327–334, 2023, doi: 10.1109/OAJPE.2023.3270223.

[225] S. K. Sahu, M. Roy, S. Dutta, D. Ghosh, and D. K. Mohanta, "Machine learning based adaptive fault diagnosis considering hosting capacity amendment in active distribution network," *Electr. Power Syst. Res.*, vol. 216, Mar. 2023, Art. no. 109025, doi: 10.1016/j.epsr.2022.109025.

[226] C. C. Liu, H. Chen, J. Shi, and L. Chen, "Self-supervised learning method for consumer-level behind-the-meter PV estimation," *Appl. Energy*, vol. 326, Nov. 2022, Art. no. 119961, doi: 10.1016/j.apenergy.2022.119961.

[227] Y. Lu, Y. Xiang, Y. Huang, B. Yu, L. Weng, and J. Liu, "Deep reinforcement learning based optimal scheduling of active distribution system considering distributed generation, energy storage and flexible load," *Energy*, vol. 271, May 2023, Art. no. 127087, doi: 10.1016/j.energy.2023.127087.

[228] V. Bassi, L. F. Ochoa, T. Alpcan, and C. Leckie, "Electrical model-free voltage calculations using neural networks and smart meter data," *IEEE Trans. Smart Grid*, vol. 14, no. 4, pp. 3271–3282, Jul. 2022, doi: 10.1109/TSG.2022.3227602.

[229] K. Mahmud and G. E. Town, "A review of computer tools for modeling electric vehicle energy requirements and their impact on power distribution networks," *Appl. Energy*, vol. 172, pp. 337–359, Jun. 2016, doi: 10.1016/j.apenergy.2016.03.100.

[230] *Power Engineering Software—Wikipedia*. Accessed: Jun. 12, 2023. [Online]. Available: https://en.wikipedia.org/wiki/Power_engineering_software

[231] *Top Ten Software for Electrical Design, Analysis and Simulation of T&D Networks | EEP*. Accessed: Jun. 12, 2023. [Online]. Available: https://electrical-engineering-portal.com/electrical-design-analysis-simulation-td-networks

[232] *PowerFactory—DIgSILENT*. Accessed: Jun. 13, 2023. [Online]. Available: https://www.digsilent.de/en/powerfactory.html

[233] M. M. Sánchez-Mora, D. L. Bernal-Romero, O. D. Montoya, W. M. Villa-Acevedo, and J. M. López-Lezama, "Solving the optimal reactive power dispatch problem through a Python-DIgSILENT interface," *Computation*, vol. 10, no. 8, p. 128, Jul. 2022, doi: 10.3390/computation10080128.

[234] H. Alnawafah, R. Sarrias-Mena, A. Harb, L. M. Fernández-Ramírez, and F. Llorens-Iborra, "Evaluating the inertia of the Jordanian power grid," *Comput. Electr. Eng.*, vol. 109, Aug. 2023, Art. no. 108748, doi: 10.1016/j.compeleceng.2023.108748.

[235] H. Alsharif, M. Jalili, and K. N. Hasan, "Power system frequency stability using optimal sizing and placement of battery energy storage system under uncertainty," *J. Energy Storage*, vol. 50, Jun. 2022, Art. no. 104610, doi: 10.1016/j.est.2022.104610.

[236] S. Lim, D. Choi, S. H. Lee, C. Kang, and J.-W. Park, "Frequency stability enhancement of low-inertia large-scale power system based on grey wolf optimization," *IEEE Access*, vol. 10, pp. 11657–11668, 2022, doi: 10.1109/ACCESS.2022.3146710.

[237] M. Wang and J. V. Milanovic, "The impacts of demand side management on combined frequency and angular stability of the power system," *IEEE Trans. Power Syst.*, vol. 38, no. 4, pp. 3775–3786, Jul. 2022, doi: 10.1109/tpwrs.2022.3203887.

[238] H. Alsharif, M. Jalili, and K. N. Hasan, "An adaptive charge control strategy for participation of neighbourhood battery energy storage systems in frequency stability," *J. Energy Storage*, vol. 67, Sep. 2023, Art. no. 107630, doi: 10.1016/j.est.2023.107630.

[239] A. Radovanović and J. V. Milanović, "Deep learning-based equivalent modelling of hybrid RES plant for efficient, repetitive power system transient stability studies," *IEEE Trans. Power Syst.*, early access, May 30, 2023, doi: 10.1109/TPWRS.2023.3281498.

[240] A. Assouak, R. Benabid, and A. A. Ladjici, "Optimal coordination of directional overcurrent relays with non-standard multi-characteristics for power systems transient instability protection," *Electr. Eng.*, vol. 104, no. 5, pp. 3697–3715, Oct. 2022, doi: 10.1007/S00202-022-01554-Z.

[241] R. Aljarrah, H. Marzooghi, and V. Terzija, "Mitigating the impact of fault level shortfall in future power systems with high penetration of converter-interfaced renewable energy sources," *Int. J. Electr. Power Energy Syst.*, vol. 149, Jul. 2023, Art. no. 109058, doi: 10.1016/j.ijepes.2023.109058.

[242] A. A. Shobole, "Multi-agent systems based adaptive protection for smart distribution network," *Electric Power Compon. Syst.*, vol. 49, nos. 18–19, pp. 1432–1444, Nov. 2021, doi: 10.1080/15325008.2022.2131937.

[243] Y. Dai, R. Preece, and M. Panteli, "Risk assessment of cascading failures in power systems with increasing wind penetration," *Electr. Power Syst. Res.*, vol. 211, Oct. 2022, Art. no. 108392, doi: 10.1016/j.epsr.2022.108392.

[244] R. Aljarrah, M. Al-Omary, D. Alshabi, Q. Salem, S. Alnaser, D. Cetenovic, and M. Karimi, "Application of artificial neural network-based tool for short circuit currents estimation in power systems with high penetration of power electronics-based renewables," *IEEE Access*, vol. 11, pp. 20051–20062, 2023, doi: 10.1109/ACCESS.2023.3249296.

[245] J. F. Piñeros, "Intelligent model to automatically determine and verify distance relays settings," *Electr. Power Syst. Res.*, vol. 217, Apr. 2023, Art. no. 109137, doi: 10.1016/j.epsr.2023.109137.

[246] T. Tumiran, L. M. Putranto, R. Irnawan, S. Sarjiya, C. F. Nugraha, A. Priyanto, and I. Savitri, "Power system planning assessment for optimizing renewable energy integration in the Maluku electricity system," *Sustainability*, vol. 14, no. 14, p. 8436, Jul. 2022, doi: 10.3390/su14148436.

[247] M. Z. Oskouei and H. Mehrjerdi, "Multi-stage proactive scheduling of strategic DISCOs in mutual interaction with cloud energy storage and deferrable loads," *IEEE Trans. Sustain. Energy*, vol. 14, no. 3, pp. 1411–1424, Jul. 2023, doi: 10.1109/TSTE.2022.3233872.

[248] E. S. Jimenez, T. T. Hoang, A. N. Cuppen, N.-K.-C. Nair, and A. Ukil, "Topology comparative assessment for hybrid medium-voltage AC/DC networks," *Electr. Power Syst. Res.*, vol. 222, Sep. 2023, Art. no. 109491, doi: 10.1016/j.epsr.2023.109491.

[249] M. Shahzad, A. Qadir, N. Ullah, Z. Mahmood, N. M. Saad, and S. S. A. Ali, "Optimization of on-grid hybrid renewable energy system: A case study on azad Jammu and Kashmir," *Sustainability*, vol. 14, no. 10, p. 5757, May 2022, doi: 10.3390/su14105757.

[250] M. F. Ishraque, A. Rahman, S. A. Shezan, and S. M. Muyeen, "Grid connected microgrid optimization and control for a coastal island in the Indian ocean," *Sustainability*, vol. 14, no. 24, p. 16697, Dec. 2022, doi: 10.3390/su142416697.

[251] S. Arif, A. E. Rabbi, S. U. Ahmed, M. S. Hossain Lipu, T. Jamal, T. Aziz, M. R. Sarker, A. Riaz, T. Alharbi, and M. M. Hussain, "Enhancement of solar PV hosting capacity in a remote industrial microgrid: A methodical techno-economic approach," *Sustainability*, vol. 14, no. 14, p. 8921, Jul. 2022, doi: 10.3390/su14148921.

[252] D. Chathurangi, U. Jayatunga, and S. Perera, "Recent investigations on the evaluation of solar PV hosting capacity in LV distribution networks constrained by voltage rise," *Renew. Energy*, vol. 199, pp. 11–20, Nov. 2022, doi: 10.1016/j.renene.2022.08.120.

[253] A. Simarro-García, R. Villena-Ruiz, A. Honrubia-Escribano, and E. Gómez-Lázaro, "Impacts of electric vehicle charging stations on a Greek distribution network," in *Proc. CIRED Porto Work. E-Mobility Power Distrib. Syst.*, 2022, pp. 452–456, doi: 10.1049/ICP.2022.074710.1049/ICP.2022.0747.

[254] H. H. Fayek, F. H. Fayek, and E. Rusu, "Pharmacophore-Modeling-Based optimal placement and sizing of large-scale energy storage stations in a power system including wind farms," *Appl. Sci.*, vol. 13, no. 10, p. 6175, May 2023, doi: 10.3390/app13106175.

[255] M. T. Rahman, K. N. Hasan, and P. Sokolowski, "Evaluation of wind farm aggregation using probabilistic clustering algorithms for power system stability assessment," *Sustain. Energy, Grids Netw.*, vol. 30, Jun. 2022, Art. no. 100678, doi: 10.1016/j.segan.2022.100678.

[256] M. Alzubaidi, K. N. Hasan, and L. Meegahapola, "Impact of probabilistic modelling of wind speed on power system voltage profile and voltage stability analysis," *Electr. Power Syst. Res.*, vol. 206, May 2022, Art. no. 107807, doi: 10.1016/j.epsr.2022.107807.

[257] H. H. Fayek and O. H. Abdalla, "Operation of the Egyptian power grid with maximum penetration level of renewable energies using corona virus optimization algorithm," *Smart Cities*, vol. 5, no. 1, pp. 34–53, Jan. 2022, doi: 10.3390/smartcities5010003.

[258] *PSS®SINCAL Power System Planning and Analysis Software—PSS® Power System Simulation and Modeling Software—Global*. Accessed: Jun. 13, 2023. [Online]. Available: https://www.siemens.com/global/en/products/energy/grid-software/planning/pss-software/pss-sincal.html

[259] S. Affijulla and P. Tripathy, ''A robust fault detection and discrimination technique for transmission lines,'' *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 6348–6358, Nov. 2018, doi: 10.1109/TSG.2017.2709546.

[260] R. Deltuva, R. Lukoč ius, and K. Otas, ''Dynamic stability analysis of isolated power system,'' *Appl. Sci.*, vol. 12, no. 14, p. 7220, Jul. 2022, doi: 10.3390/app12147220.

[261] S. M. Tercan, A. Demirci, E. Gokalp, and U. Cali, ''Maximizing self-consumption rates and power quality towards two-stage evaluation for solar energy and shared energy storage empowered microgrids,'' *J. Energy Storage*, vol. 51, Jul. 2022, Art. no. 104561, doi: 10.1016/j.est.2022.104561.

[262] *OpenDSS Download | SourceForge.net*. Accessed: Jun. 13, 2023. [Online]. Available: https://sourceforge.net/projects/electricdss/

[263] A. Abbas and B. Chowdhury, ''Stochastic optimization framework for realizing combined value streams from customer-side resources—Self service and distribution system operations,'' *IEEE Trans. Smart Grid*, vol. 14, no. 5, pp. 3573–3583, Sep. 2023, doi: 10.1109/TSG.2023.3239412.

[264] A. Sahu, V. Venkatraman, and R. Macwan, ''Reinforcement learning environment for cyber-resilient power distribution system,'' *IEEE Access*, vol. 11, pp. 127216–127228, 2023, doi: 10.1109/ACCESS.2023.3282182.

[265] F. Aboshady, O. Ceylan, A. F. Zobaa, A. Ozdemir, G. Taylor, and I. Pisica, ''Sequentially coordinated and cooperative volt/var control of PV inverters in distribution networks,'' *Electronics*, vol. 12, no. 8, p. 1765, Apr. 2023, doi: 10.3390/electronics12081765.

[266] R. Wagle, P. Sharma, C. Sharma, M. Amin, J. L. Rueda, and F. Gonzalez-Longatt, ''Optimal power flow-based reactive power control in smart distribution network using real-time cyber-physical co-simulation framework,'' *IET Gener., Transmiss. Distrib.*, vol. 17, no. 20, pp. 4489–4502, Oct. 2023, doi: 10.1049/gtd2.12786.

[267] R. Dugan, ''Introduction to the OpenDSS,'' Tech. Rep., 2009. Accessed: Jan. 30, 2024. [Online]. Available: https://spinengenharia.com.br/wp-content/uploads/2019/01/Introduction-to-the-OpenDSS.pdf

[268] M. Toledo-Orozco, E. Bravo-Padilla, C. Álvarez-Bel, D. Morales-Jadan, and L. Gonzalez-Morales, ''Methodological evaluation to integrate charging stations for electric vehicles in a tram system using OpenDSS—A case study in Ecuador,'' *Sustainability*, vol. 15, no. 8, p. 6382, Apr. 2023, doi: 10.3390/su15086382.

[269] G. W. Chang, N. C. Chinh, and C. Sinatra, ''Equilibrium optimizer-based approach of PV generation planning in a distribution system for maximizing hosting capacity,'' *IEEE Access*, vol. 10, pp. 118108–118122, 2022, doi: 10.1109/ACCESS.2022.3220256.

[270] *Power Distribution System | Electrical Simulation Software | Synergi Electric*. Accessed: Jun. 13, 2023. [Online]. Available: https://www.dnv.com/services/power-distribution-system-and-electrical-simulation-software-synergi-electric-5005

[271] U. Azhar, M. Rizwan, W. Shen, and M. Korki, ''Performance analysis of a low voltage distribution network in Pakistan under high penetration of rooftop solar PV systems,'' in *Proc. IEEE PES 14th Asia–Pacific Power Energy Eng. Conf. (APPEEC)*, Nov. 2022, pp. 1–6, doi: 10.1109/APPEEC53445.2022.10072154.

[272] Engr. A. J. L. Baco and Atty. D. O. Albina, ''Efficient smart grid data updating and diagnostics (don't short) for transformer loading management,'' in *Proc. 5th Int. Conf. Power Eng. Renew. Energy (ICPERE)*, vol. 1, Nov. 2022, pp. 1–6, doi: 10.1109/ICPERE56870.2022.10037393.

[273] J. Xie, M. C. W. Kintner-Meyer, S. Sridhar, X. Chen, T. E. McDermott, W. Du, K. P. Schneider, H. Wang, J. C. Bedoya, K. Mo, and M. Ramesh, ''Impact analysis of future electric vehicles using model of real distribution feeders,'' in *Proc. IEEE Power Energy Soc. Innov. Smart Grid Technol. Conf. (ISGT)*, Jan. 2023, pp. 1–5, doi: 10.1109/ISGT51731.2023.10066428.

[274] *PSI Neplan—Power System Analysis*. Accessed: Jun. 14, 2023. [Online]. Available: https://www.neplan.ch/

[275] O. B. Adewumi, G. Fotis, V. Vita, D. Nankoo, and L. Ekonomou, ''The impact of distributed energy storage on distribution and transmission networks' power quality,'' *Appl. Sci.*, vol. 12, no. 13, p. 6466, Jun. 2022, doi: 10.3390/app12136466.

[276] O. Agbonaye, P. Keatley, Y. Huang, F. O. Odiase, and N. Hewitt, ''Value of demand flexibility for managing wind energy constraint and curtailment,'' *Renew. Energy*, vol. 190, pp. 487–500, May 2022, doi: 10.1016/j.renene.2022.03.131.

[277] M. B. Shafik, Z. M. S. Elbarbary, B. Siqi, A. M. Azmy, and M. G. Hussien, ''Distribution networks reliability assessment considering distributed automation system with penetration of DG units and SOP devices,'' *Energy Rep.*, vol. 9, pp. 6199–6210, Dec. 2023, doi: 10.1016/j.egyr.2023.05.224.

[278] *CYME Power Engineering Software*. Accessed: Jun. 14, 2023. [Online]. Available: https://www.cyme.com/software/

[279] M. Al-Saffar, S. Zhang, A. Nassif, and P. Musilek, ''Assessment of photovoltaic hosting capacity of existing distribution circuits,'' in *Proc. IEEE Can. Conf. Electr. Comput. Eng. (CCECE)*, May 2019, pp. 1–4, doi: 10.1109/CCECE.2019.8861957.

[280] J. A. Azzolini, M. J. Reno, J. Yusuf, S. Talkington, and S. Grijalva, ''Calculating PV hosting capacity in low-voltage secondary networks using only smart meter data,'' in *Proc. IEEE Power Energy Soc. Innov. Smart Grid Technol. Conf. (ISGT)*, Jan. 2023, pp. 1–5, doi: 10.1109/ISGT51731.2023.10066372.

[281] M. Al-Saffar and P. Musilek, ''Reinforcement learning-based distributed BESS management for mitigating overvoltage issues in systems with high PV penetration,'' *IEEE Trans. Smart Grid*, vol. 11, no. 4, pp. 2980–2994, Jul. 2020, doi: 10.1109/TSG.2020.2972208.

[282] A. M. Mahmoud, S. H. E. Abdel Aleem, A. Y. Abdelaziz, and M. Ezzat, ''Towards maximizing hosting capacity by optimal planning of active and reactive power compensators and voltage regulators: Case study,'' *Sustainability*, vol. 14, no. 20, p. 13299, Oct. 2022, doi: 10.3390/su142013299.

[283] *Estrategias Diferenciadas S.A.* Accessed: Jun. 13, 2023. [Online]. Available: https://www.edsa.com/

[284] *Real-Time Simulation—Real-Time Solutions*. Accessed: Jun. 14, 2023. [Online]. Available: https://www.opal-rt.com/

[285] *EasyPower Arc Flash Analysis Software*. Accessed: Jun. 14, 2023. [Online]. Available: https://www.easypower.com/

[286] *DSATools*. Accessed: Jun. 14, 2023. [Online]. Available: https://www.dsatools.com/

[287] *HOMER—Hybrid Renewable and Distributed Generation System Design Software*. Accessed: Jun. 14, 2023.[Online]. Available: https://www.homerenergy.com/

[288] Y. Naderi, S. H. Hosseini, S. Ghassem Zadeh, B. Mohammadi-Ivatloo, J. C. Vasquez, and J. M. Guerrero, ''An overview of power quality enhancement techniques applied to distributed generation in electrical distribution networks,'' *Renew. Sustain. Energy Rev.*, vol. 93, pp. 201–214, Oct. 2018, doi: 10.1016/j.rser.2018.05.013.

[289] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi, ''Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality,'' *Renew. Sustain. Energy Rev.*, vol. 91, pp. 1205–1230, Aug. 2018, doi: 10.1016/j.rser.2018.03.068.

[290] K. Prakash, M. Ali, M. N. I. Siddique, A. A. Chand, N. M. Kumar, D. Dong, and H. R. Pota, ''A review of battery energy storage systems for ancillary services in distribution grids: Current status, challenges and future directions,'' *Frontiers Energy Res.*, vol. 10, Sep. 2022, Art. no. 971704, doi: 10.3389/FENRG.2022.971704.

[291] P. Chaudhary and M. Rizwan, ''Voltage regulation mitigation techniques in distribution system with high PV penetration: A review,'' *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3279–3287, Feb. 2018, doi: 10.1016/j.rser.2017.10.017.

[292] M. S. Ali, M. M. Haque, and P. Wolfs, ''A review of topological ordering based voltage rise mitigation methods for LV distribution networks with high levels of photovoltaic penetration,'' *Renew. Sustain. Energy Rev.*, vol. 103, pp. 463–476, Apr. 2019, doi: 10.1016/j.rser.2018.12.049.

[293] S. A. Aleem, S. M. S. Hussain, and T. S. Ustun, ''A review of strategies to increase PV penetration level in smart grids,'' *Energies*, vol. 13, no. 3, p. 636, Feb. 2020, doi: 10.3390/en13030636.

[294] M. Usama, H. Mokhlis, M. Moghavvemi, N. N. Mansor, M. A. Alotaibi, M. A. Muhammad, and A. A. Bajwa, ''A comprehensive review on protection strategies to mitigate the impact of renewable energy sources on interconnected distribution networks,'' *IEEE Access*, vol. 9, pp. 35740–35765, 2021, doi: 10.1109/ACCESS.2021.3061919.

[295] K. Alboaouh and S. Mohagheghi, ''Voltage, var and Watt optimization for a distribution system with high PV penetration: A probabilistic study,'' *Electr. Power Syst. Res.*, vol. 180, Mar. 2020, Art. no. 106159, doi: 10.1016/j.epsr.2019.106159.

[296] M. Dubravac, K. Fekete, D. Topić, and M. Barukč ić, ''Voltage optimization in PV-rich distribution networks—A review,'' *Appl. Sci.*, vol. 12, no. 23, p. 12426, Dec. 2022, doi: 10.3390/app122312426.

[297] I. Hamdan, A. Alfouly, and M. A. Ismeil, "A literature review on hosting capacity methodologies and inverter control technologies for photovoltaic system," in *Proc. IEEE Conf. Power Electron. Renew. Energy (CPERE)*, Feb. 2023, pp. 1–7, doi: 10.1109/CPERE56564.2023.10119630.

[298] N. Kongtrakul, W. Wangdee, and S. Chantaraskul, "Comprehensive review and a novel technique on voltage unbalance compensation," *IET Smart Grid*, vol. 6, no. 4, pp. 331–358, Aug. 2023, doi: 10.1049/stg2.12106.

[299] A. Alizadeh, I. Kamwa, A. Moeini, and S. M. Mohseni-Bonab, "Energy management in microgrids using transactive energy control concept under high penetration of renewables; a survey and case study," *Renew. Sustain. Energy Rev.*, vol. 176, Apr. 2023, Art. no. 113161, doi: 10.1016/j.rser.2023.113161.

[300] J. Alpízar-Castillo, L. Ramirez-Elizondo, and P. Bauer, "Assessing the role of energy storage in multiple energy carriers toward providing ancillary services: A review," *Energies*, vol. 16, no. 1, p. 379, Dec. 2022, doi: 10.3390/en16010379.

[301] M. Magdy, M. Elshahed, and D. K. Ibrahim, "Enhancing PV hosting capacity using smart inverters and time of use tariffs," *Iranian J. Sci. Technol., Trans. Electr. Eng.*, vol. 45, no. 3, pp. 905–920, Sep. 2021, doi: 10.1007/s40998-020-00404-7.

[302] D. Chathurangi, U. Jayatunga, S. Perera, A. P. Agalgaonkar, and T. Siyambalapitiya, "Comparative evaluation of solar PV hosting capacity enhancement using volt-var and volt-watt control strategies," *Renew. Energy*, vol. 177, pp. 1063–1075, Nov. 2021, doi: 10.1016/j.renene.2021.06.037.

[303] H. A. Villarroel-Gutiérrez, J. Morales, and M. Molina, "A novel methodology for dynamic voltage support with adaptive schemes in photovoltaic generators," *Electr. Eng.*, vol. 104, no. 6, pp. 4103–4123, Dec. 2022, doi: 10.1007/s00202-022-01600-w.

[304] V. Kumar Tatikayala and S. Dixit, "Multi-stage voltage control in high photovoltaic based distributed generation penetrated distribution system considering smart inverter reactive power capability," *Ain Shams Eng. J.*, vol. 15, no. 1, Jan. 2024, Art. no. 102265, doi: 10.1016/j.asej.2023.102265.

[305] B. Jaramillo-Leon, S. Zambrano-Asanza, J. F. Franco, and J. B. Leite, "Simulation-based optimization framework to increase distribution system photovoltaic hosting capacity through optimal settings of smart inverter volt-var control function," *Electr. Power Syst. Res.*, vol. 215, Feb. 2023, Art. no. 108971, doi: 10.1016/j.epsr.2022.108971.

[306] E. M. Ahmed, S. Rakoč ević, M. Ć alasan, Z. M. Ali, H. M. Hasanien, R. A. Turky, and S. H. E. A. Aleem, "BONMIN solver-based coordination of distributed FACTS compensators and distributed generation units in modern distribution networks," *Ain Shams Eng. J.*, vol. 13, no. 4, Jun. 2022, Art. no. 101664, doi: 10.1016/j.asej.2021.101664.

[307] A. Eid, S. Kamel, H. M. Zawbaa, and M. Dardeer, "Improvement of active distribution systems with high penetration capacities of shunt reactive compensators and distributed generators using bald eagle search," *Ain Shams Eng. J.*, vol. 13, no. 6, Nov. 2022, Art. no. 101792, doi: 10.1016/j.asej.2022.101792.

[308] O. D. Montoya, W. Gil-González, and J. C. Hernández, "Efficient integration of fixed-step capacitor banks and D-STATCOMs in radial and meshed distribution networks considering daily operation curves," *Energies*, vol. 16, no. 8, p. 3532, Apr. 2023, doi: 10.3390/en16083532.

[309] A. M. Shaheen, R. A. El-Sehiemy, A. Ginidi, A. M. Elsayed, and S. F. Al-Gahtani, "Optimal allocation of PV-STATCOM devices in distribution systems for energy losses minimization and voltage profile improvement via hunter-prey-based algorithm," *Energies*, vol. 16, no. 6, p. 2790, Mar. 2023, doi: 10.3390/en16062790.

[310] M. Kandasamy, R. Thangavel, T. Arumugam, S. Kumaravel, S. Aruchamy, W.-W. Kim, and Z. W. Geem, "Strategic incorporation of DSTATCOM and distributed generations in balanced and unbalanced radial power distribution networks considering time varying loads," *Energy Rep.*, vol. 9, pp. 4345–4359, Dec. 2023, doi: 10.1016/j.egyr.2023.03.076.

[311] N. Tshivhase, A. N. Hasan, and T. Shongwe, "A fault level-based system to control voltage and enhance power factor through an on-load tap changer and distributed generators," *IEEE Access*, vol. 9, pp. 34023–34039, 2021, doi: 10.1109/ACCESS.2021.3061622.

[312] M. Aydin, S. Alnaser, and S. Althaher, "Using OLTC-fitted distribution transformer to increase residential PV hosting capacity: Decentralized voltage management approach," *Energies*, vol. 15, no. 13, p. 4836, Jul. 2022, doi: 10.3390/en15134836.

[313] J. Bendík, M. Cenký, B. Cintula, A. Beláá, Ž. Eleschová, and P. Janiga, "Stochastic approach for increasing the PV hosting capacity of a low-voltage distribution network," *Processes*, vol. 11, no. 1, p. 9, Dec. 2022, doi: 10.3390/pr11010009.

[314] A. I. M. Ali, H. H. H. Mousa, H. R. A. Mohamed, S. Kamel, A. S. Hassan, Z. M. Alaas, E. E. M. Mohamed, and A.-R.-Y. Abdallah, "An enhanced P&O MPPT algorithm with concise search area for grid-tied PV systems," *IEEE Access*, vol. 11, pp. 79408–79421, 2023, doi: 10.1109/access.2023.3298106.

[315] R. Fachrizal, U. H. Ramadhani, J. Munkhammar, and J. Widén, "Combined PV–EV hosting capacity assessment for a residential LV distribution grid with smart EV charging and PV curtailment," *Sustain. Energy, Grids Netw.*, vol. 26, Jun. 2021, Art. no. 100445, doi: 10.1016/j.segan.2021.100445.

[316] A. F. Cortés Borray, J. Merino, E. Torres, A. Garcés, and J. Mazón, "Centralised coordination of EVs charging and PV active power curtailment over multiple aggregators in low voltage networks," *Sustain. Energy, Grids Netw.*, vol. 27, Sep. 2021, Art. no. 100470, doi: 10.1016/j.segan.2021.100470.

[317] P. Verma, N. Katal, B. Sharma, S. Chowdhury, A. Mehbodniya, J. L. Webber, and A. Bostani, "Voltage rise mitigation in PV rich LV distribution networks using DC/DC converter level active power curtailment method," *Energies*, vol. 15, no. 16, p. 5901, Aug. 2022, doi: 10.3390/en15165901.

[318] E. Memmel, S. Schlüters, R. Völker, F. Schuldt, K. Von Maydell, and C. Agert, "Forecast of renewable curtailment in distribution grids considering uncertainties," *IEEE Access*, vol. 9, pp. 60828–60840, 2021, doi: 10.1109/ACCESS.2021.3073754.

[319] E. Memmel, T. Steens, S. Schlüters, R. Völker, F. Schuldt, and K. Von Maydell, "Predicting renewable curtailment in distribution grids using neural networks," *IEEE Access*, vol. 11, pp. 20319–20336, 2023, doi: 10.1109/ACCESS.2023.3249459.

[320] C. K. Das, O. Bass, T. S. Mahmoud, G. Kothapalli, N. Mousavi, D. Habibi, and M. A. S. Masoum, "Optimal allocation of distributed energy storage systems to improve performance and power quality of distribution networks," *Appl. Energy*, vol. 252, Oct. 2019, Art. no. 113468, doi: 10.1016/j.apenergy.2019.113468.

[321] A. Alzahrani, H. Alharthi, and M. Khalid, "Minimization of power losses through optimal battery placement in a distributed network with high penetration of photovoltaics," *Energies*, vol. 13, no. 1, p. 140, Dec. 2019, doi: 10.3390/en13010140.

[322] M. Rawa, A. Abusorrah, Y. Al-Turki, S. Mekhilef, M. H. Mostafa, Z. M. Ali, and S. H. E. A. Aleem, "Optimal allocation and economic analysis of battery energy storage systems: Self-consumption rate and hosting capacity enhancement for microgrids with high renewable penetration," *Sustainability*, vol. 12, no. 23, p. 10144, Dec. 2020, doi: 10.3390/su122310144.

[323] W. Y. Atmaja, and L. M. Putranto, "Battery energy storage system to reduce voltage rise under high penetration of customer-scale photovoltaics," *Int. J. Sustain. Energy*, vol. 41, no. 11, pp. 2150–2168, Dec. 2022, doi: 10.1080/14786451.2022.2136176.

[324] S. Khunkitti, P. Boonluk, and A. Siritaratiwat, "Optimal location and sizing of BESS for performance improvement of distribution systems with high DG penetration," *Int. Trans. Electr. Energy Syst.*, vol. 2022, pp. 1–16, Jun. 2022, doi: 10.1155/2022/6361243.

[325] L. Haupt, M. Schöpf, L. Wederhake, and M. Weibelzahl, "The influence of electric vehicle charging strategies on the sizing of electrical energy storage systems in charging hub microgrids," *Appl. Energy*, vol. 273, Sep. 2020, Art. no. 115231, doi: 10.1016/j.apenergy.2020.115231.

[326] M. Kamruzzaman and M. Benidris, "A reliability-constrained demand response-based method to increase the hosting capacity of power systems to electric vehicles," *Int. J. Electr. Power Energy Syst.*, vol. 121, Oct. 2020, Art. no. 106046, doi: 10.1016/j.ijepes.2020.106046.

[327] G. Pillai, M. Allison, T. P. Tun, K. C. Jyothi, and E. K. Babu, "Facilitating higher photovoltaic penetration in residential distribution networks using demand side management and active voltage control," *Eng. Rep.*, vol. 3, no. 10, Oct. 2021, Art. no. e12410, doi: 10.1002/eng2.12410.

[328] Y.-J. Son, S.-H. Lim, S.-G. Yoon, and P. P. Khargonekar, "Residential demand response-based load-shifting scheme to increase hosting capacity in distribution system," *IEEE Access*, vol. 10, pp. 18544–18556, 2022, doi: 10.1109/ACCESS.2022.3151172.

[329] A. Bakhshinejad, A. Tavakoli, and M. M. Moghaddam, ''Modeling and simultaneous management of electric vehicle penetration and demand response to improve distribution network performance,'' *Electr. Eng.*, vol. 103, no. 1, pp. 325–340, Feb. 2021, doi: 10.1007/S00202-020-01083-7.

[330] Z. Lu, X. Xu, and Z. Yan, ''Data-driven stochastic programming for energy storage system planning in high PV-penetrated distribution network,'' *Int. J. Electr. Power Energy Syst.*, vol. 123, Dec. 2020, Art. no. 106326, doi: 10.1016/j.ijepes.2020.106326.

[331] J. F. B. Sousa, C. L. T. Borges, and J. Mitra, ''PV hosting capacity of LV distribution networks using smart inverters and storage systems: A practical margin,'' *IET Renew. Power Gener.*, vol. 14, no. 8, pp. 1332–1339, Jun. 2020, doi: 10.1049/iet-rpg.2019.1054.

[332] N. Tshivhase, A. N. Hasan, and T. Shongwe, ''An average voltage approach to control energy storage device and tap changing transformers under high distributed generation,'' *IEEE Access*, vol. 9, pp. 108731–108753, 2021, doi: 10.1109/ACCESS.2021.3101463.

[333] A. Ali, K. Mahmoud, and M. Lehtonen, ''Maximizing hosting capacity of uncertain photovoltaics by coordinated management of OLTC, VAr sources and stochastic EVs,'' *Int. J. Electr. Power Energy Syst.*, vol. 127, May 2021, Art. no. 106627, doi: 10.1016/j.ijepes.2020.106627.

[334] W. Ma, W. Wang, Z. Chen, and R. Hu, ''A centralized voltage regulation method for distribution networks containing high penetrations of photovoltaic power,'' *Int. J. Electr. Power Energy Syst.*, vol. 129, Jul. 2021, Art. no. 106852, doi: 10.1016/j.ijepes.2021.106852.

[335] R. Haider and A. M. Annaswamy, ''A hybrid architecture for volt-var control in active distribution grids,'' *Appl. Energy*, vol. 312, Apr. 2022, Art. no. 118735, doi: 10.1016/j.apenergy.2022.118735.

[336] U. Tamrakar, D. Shrestha, M. Maharjan, B. Bhattarai, T. Hansen, and R. Tonkoski, ''Virtual inertia: Current trends and future directions,'' *Appl. Sci.*, vol. 7, no. 7, p. 654, Jun. 2017, doi: 10.3390/app7070654.

[337] M. Bajaj and A. Kumar Singh, ''Hosting capacity enhancement of renewable-based distributed generation in harmonically polluted distribution systems using passive harmonic filtering,'' *Sustain. Energy Technol. Assessments*, vol. 44, Apr. 2021, Art. no. 101030, doi: 10.1016/j.seta.2021.101030.

[338] M. Bajaj and A. K. Singh, ''Optimal design of passive power filter for enhancing the harmonic-constrained hosting capacity of renewable DG systems,'' *Comput. Electr. Eng.*, vol. 97, Jan. 2022, Art. no. 107646, doi: 10.1016/j.compeleceng.2021.107646.

[339] T. A. H. Alghamdi, F. Anayi, and M. Packianather, ''Optimal design of passive power filters using the MRFO algorithm and a practical harmonic analysis approach including uncertainties in distribution networks,'' *Energies*, vol. 15, no. 7, p. 2566, Apr. 2022, doi: 10.3390/en15072566.

[340] T. M. T. Thentral, S. Usha, R. Palanisamy, A. Geetha, A. M. Alkhudaydi, and N. K. Sharma, ''An energy efficient modified passive power filter for power quality enhancement in electric drives,'' *Frontiers Energy Res.*, vol. 10, Oct. 2022, Art. no. 989857, doi: 10.3389/FENRG.2022.989857.

[341] M. Bajaj and A. K. Singh, ''Increasing renewable energy penetration in harmonically polluted distribution grids using passive filtering: A comparative assessment of common filter types,'' *Electr. Eng.*, vol. 104, no. 5, pp. 2979–3005, Oct. 2022, doi: 10.1007/S00202-022-01521-8.

[342] S. R. Das, A. K. Mishra, P. K. Ray, S. R. Salkuti, and S.-C. Kim, ''Application of artificial intelligent techniques for power quality improvement in hybrid microgrid system,'' *Electronics*, vol. 11, no. 22, p. 3826, Nov. 2022, doi: 10.3390/electronics11223826.

[343] M. Bajaj and A. K. Singh, ''Performance assessment of hybrid active filtering technique to enhance the hosting capacity of distorted grids for renewable energy systems,'' *Int. J. Energy Res.*, vol. 46, no. 3, pp. 2783–2809, Mar. 2022, doi: 10.1002/er.7345.

[344] F. Alasali, K. Nusair, H. Foudeh, W. Holderbaum, A. Vinayagam, and A. Aziz, ''Modern optimal controllers for hybrid active power filter to minimize harmonic distortion,'' *Electronics*, vol. 11, no. 9, p. 1453, Apr. 2022, doi: 10.3390/electronics11091453.

[345] J. Jung, A. Onen, R. Arghandeh, and R. P. Broadwater, ''Coordinated control of automated devices and photovoltaic generators for voltage rise mitigation in power distribution circuits,'' *Renew. Energy*, vol. 66, pp. 532–540, Jun. 2014, doi: 10.1016/j.renene.2013.12.039.

[346] S. K. Sahu and D. Ghosh, ''Hosting capacity enhancement in distribution system in highly trenchant photo-voltaic environment: A hardware in loop approach,'' *IEEE Access*, vol. 8, pp. 14440–14451, 2020, doi: 10.1109/ACCESS.2019.2962263.

[347] Y. Yao, F. Ding, K. Horowitz, and A. Jain, ''Coordinated inverter control to increase dynamic PV hosting capacity: A real-time optimal power flow approach,'' *IEEE Syst. J.*, vol. 16, no. 2, pp. 1933–1944, Jun. 2022, doi: 10.1109/JSYST.2021.3071998.

[348] T. Kaewnukultorn, S. B. Sepúlveda-Mora, and S. Hegedus, ''Characterization of voltage stabilization functions of residential PV inverters in a power hardware-in-the-loop environment,'' *IEEE Access*, vol. 10, pp. 114802–114813, 2022, doi: 10.1109/ACCESS.2022.3217472.

[349] R. Chen, C. Yang, Y. Ma, W. Wang, M. Wang, and X. Du, ''Online learning predictive power coordinated control strategy for off-road hybrid electric vehicles considering the dynamic response of engine generator set,'' *Appl. Energy*, vol. 323, Oct. 2022, Art. no. 119592, doi: 10.1016/j.apenergy.2022.119592.

[350] A. S. Abbas, A. A. A. El-Ela, and R. A. El-Sehiemy, ''Maximization approach of hosting capacity based on uncertain renewable energy resources using network reconfiguration and soft open points,'' *Int. Trans. Electr. Energy Syst.*, vol. 2022, pp. 1–12, Feb. 2022, doi: 10.1155/2022/2947965.

[351] M. Taghavi, H. Delkhosh, M. P. Moghaddam, and A. S. Fini, ''Hosting capacity enhancement of hybrid AC/DC distribution network based on static and dynamic reconfiguration,'' *IET Gener., Transmiss. Distrib.*, vol. 2023, pp. 1–15, Feb. 2023, doi: 10.1049/GTD2.12799.

[352] M. Amini, A. Jalilian, and M. R. Pour Behbahani, ''Fast network reconfiguration in harmonic polluted distribution network based on developed backward/forward sweep harmonic load flow,'' *Electr. Power Syst. Res.*, vol. 168, pp. 295–304, Mar. 2019, doi: 10.1016/j.epsr.2018.12.006.

[353] R. Čadenović and D. Jakus, ''Maximization of distribution network hosting capacity through optimal grid reconfiguration and distributed generation capacity allocation/control,'' *Energies*, vol. 13, no. 20, p. 5315, Oct. 2020, doi: 10.3390/EN13205315.

[354] M. M. Sayed, M. Y. Mahdy, S. H. E. A. Aleem, H. K. M. Youssef, and T. A. Boghdady, ''Simultaneous distribution network reconfiguration and optimal allocation of renewable-based distributed generators and shunt capacitors under uncertain conditions,'' *Energies*, vol. 15, no. 6, p. 2299, Mar. 2022, doi: 10.3390/EN15062299.

[355] A. Shaheen, A. Elsayed, A. Ginidi, R. El-Sehiemy, and E. Elattar, ''Reconfiguration of electrical distribution network-based DG and capacitors allocations using artificial ecosystem optimizer: Practical case study,'' *Alexandria Eng. J.*, vol. 61, no. 8, pp. 6105–6118, Aug. 2022, doi: 10.1016/j.aej.2021.11.035.

[356] S. Toghranegar, A. Rabiee, and A. Soroudi, ''Enhancing the unbalanced distribution network's hosting capacity for DERs via optimal load re-phasing,'' *Sustain. Cities Soc.*, vol. 87, Dec. 2022, Art. no. 104243, doi: 10.1016/j.scs.2022.104243.

[357] T. Bragatto, F. Carere, M. Cresta, F. M. Gatta, A. Geri, M. Maccioni, and M. Paulucci, ''Developing a public EV charging infrastructure in a DSO's perspective: Hosting capacity assessment and grid reinforcements on a real case study,'' *Electr. Power Syst. Res.*, vol. 221, Aug. 2023, Art. no. 109463, doi: 10.1016/j.epsr.2023.109463.

[358] M. Rahimipour Behbahani and A. Jalilian, ''Reconfiguration of harmonic polluted distribution network using modified discrete particle swarm optimization equipped with smart radial method,'' *IET Gener., Transmiss. Distrib.*, vol. 17, no. 11, pp. 2563–2575, Jun. 2023, doi: 10.1049/gtd2.12869.

[359] S. Ikeda and H. Ohmori, ''Evaluation for maximum hosting capacity of distributed generation considering active network management,'' *Int. J. Electr. Electron. Eng. Telecommun.*, vol. 10, pp. 96–102, Jul. 2018, doi: 10.18178/ijeetc.7.3.96-102.

[360] S. N. Md Saad and A. H. van der Weijde, ''Evaluating the potential of hosting capacity enhancement using integrated grid planning modeling methods,'' *Energies*, vol. 12, no. 19, p. 3610, Sep. 2019, doi: 10.3390/en12193610.

[361] B. N. F. Fanos, M. H. Soliman, H. E. A. Talaat, and M. A. Attia, ''Modern active voltage control in distribution networks, including distributed generation, using the hardware-in-the-loop technique,'' *Symmetry*, vol. 15, no. 1, p. 90, Dec. 2022, doi: 10.3390/sym15010090.

[362] D. A. Quijano, J. Wang, M. R. Sarker, and A. Padilha-Feltrin, ''Stochastic assessment of distributed generation hosting capacity and energy efficiency in active distribution networks,'' *IET Gener. Transm. Distrib.*, vol. 11, no. 18, pp. 4617–4625, Dec. 2017.

[363] R. Golnazari, S. Hasanzadeh, E. Heydarian-Forushani, and I. Kamwa, ''Coordinated active and reactive power management for enhancing PV hosting capacity in distribution networks,'' *IET Renew. Power Gener.*, vol. 2023, pp. 1–10, May 2023, doi: 10.1049/rpg2.12773.

[364] A. Ali, K. Mahmoud, and M. Lehtonen, ''Enhancing hosting capacity of intermittent wind turbine systems using bi-level optimisation considering OLTC and electric vehicle charging stations,'' *IET Renew. Power Gener.*, vol. 14, no. 17, pp. 3558–3567, Dec. 2020, doi: 10.1049/iet-rpg.2020.0837.

[365] D. A. Quijano, O. D. Melgar-Dominguez, C. Sabillon, B. Venkatesh, and A. Padilha-Feltrin, ''Increasing distributed generation hosting capacity in distribution systems via optimal coordination of electric vehicle aggregators,'' *IET Gener., Transmiss. Distrib.*, vol. 15, no. 2, pp. 359–370, Jan. 2021, doi: 10.1049/gtd2.12026.

[366] M. Mahmoodi, A. Attarha, S. Mahdi Noori R. A., P. Scott, and L. Blackhall, ''Adjustable robust approach to increase DG hosting capacity in active distribution systems,'' *Electr. Power Syst. Res.*, vol. 211, Oct. 2022, Art. no. 108347, doi: 10.1016/j.epsr.2022.108347.

[367] S. Kang, J. Kim, J.-W. Park, and S.-M. Baek, ''Reactive power management based on voltage sensitivity analysis of distribution system with high penetration of renewable energies,'' *Energies*, vol. 12, no. 8, p. 1493, Apr. 2019, doi: 10.3390/en12081493.

[368] J. Xiao, Y. Li, X. Qiao, Y. Tan, Y. Cao, and L. Jiang, ''Enhancing hosting capacity of uncertain and correlated wind power in distribution network with ANM strategies,'' *IEEE Access*, vol. 8, pp. 189115–189128, 2020, doi: 10.1109/ACCESS.2020.3030705.

[369] Y. M. Atwa, E. F. El-Saadany, M. M. A. Salama, and R. Seethapathy, ''Optimal renewable resources mix for distribution system energy loss minimization,'' *IEEE Trans. Power Syst.*, vol. 25, no. 1, pp. 360–370, Feb. 2010, doi: 10.1109/TPWRS.2009.2030276.

[370] A. Soroudi and A. Rabiee, ''Optimal multi-area generation schedule considering renewable resources mix: A real-time approach,'' *IET Gener., Transmiss. Distrib.*, vol. 7, no. 9, pp. 1011–1026, Sep. 2013, doi: 10.1049/iet-gtd.2012.0735.

[371] H. Fathabadi, ''Utilization of electric vehicles and renewable energy sources used as distributed generators for improving characteristics of electric power distribution systems,'' *Energy*, vol. 90, pp. 1100–1110, Oct. 2015, doi: 10.1016/j.energy.2015.06.063.

[372] P. Kayal and C. K. Chanda, ''Optimal mix of solar and wind distributed generations considering performance improvement of electrical distribution network,'' *Renew. Energy*, vol. 75, pp. 173–186, Mar. 2015, doi: 10.1016/j.renene.2014.10.003.

[373] P. Singh, N. K. Meena, J. Yang, E. Vega-Fuentes, and S. K. Bishnoi, ''Multi-criteria decision making monarch butterfly optimization for optimal distributed energy resources mix in distribution networks,'' *Appl. Energy*, vol. 278, Nov. 2020, Art. no. 115723, doi: 10.1016/j.apenergy.2020.115723.

[374] N. Gupta, M. Agarwal, P. Garg, and M. Bansal, ''Revenue optimization modeling for renewable energy resource mix for sustainable development,'' *J. Revenue Pricing Manag.*, vol. 20, no. 2, pp. 108–115, Apr. 2021, doi: 10.1057/S41272-021-00294-2.

[375] A. Al-Badi, ''Optimal renewable resources mix for energy loss minimization in distribution network-case study,'' *Int. J. Comput. Syst. Eng.*, vol. 3, no. 1, pp. 1–15, Oct. 2022. [Online]. Available: https://digitalcommons.fairfield.edu/ijcase/vol3/iss1/2

[376] J. J. Vidal-Amaro, P. A. Østergaard, and C. Sheinbaum-Pardo, ''Optimal energy mix for transitioning from fossil fuels to renewable energy sources—The case of the Mexican electricity system,'' *Appl. Energy*, vol. 150, pp. 80–96, Jul. 2015, doi: 10.1016/j.apenergy.2015.03.133.

[377] C. Cany, C. Mansilla, G. Mathonnière, and P. da Costa, ''Nuclear contribution to the penetration of variable renewable energy sources in a French decarbonised power mix,'' *Energy*, vol. 150, pp. 544–555, May 2018, doi: 10.1016/j.energy.2018.02.122.

[378] V. M. Maestre, A. Ortiz, and I. Ortiz, ''The role of hydrogen-based power systems in the energy transition of the residential sector,'' *J. Chem. Technol. Biotechnol.*, vol. 97, no. 3, pp. 561–574, Mar. 2022, doi: 10.1002/jctb.6938.

[379] C. Breyer et al., ''On the history and future of 100% renewable energy systems research,'' *IEEE Access*, vol. 10, pp. 78176–78218, 2022, doi: 10.1109/ACCESS.2022.3193402.

[380] N. S. Muhammed, B. Haq, D. Al Shehri, A. Al-Ahmed, M. M. Rahman, and E. Zaman, ''A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook,'' *Energy Rep.*, vol. 8, pp. 461–499, Nov. 2022, doi: 10.1016/j.egyr.2021.12.002.

[381] J. O. Abe, A. P. I. Popoola, E. Ajenifuja, and O. M. Popoola, ''Hydrogen energy, economy and storage: Review and recommendation,'' *Int. J. Hydrogen Energy*, vol. 44, no. 29, pp. 15072–15086, Jun. 2019, doi: 10.1016/j.ijhydene.2019.04.068.

[382] M. Yue, H. Lambert, E. Pahon, R. Roche, S. Jemei, and D. Hissel, ''Hydrogen energy systems: A critical review of technologies, applications, trends and challenges,'' *Renew. Sustain. Energy Rev.*, vol. 146, Aug. 2021, Art. no. 111180, doi: 10.1016/j.rser.2021.111180.

[383] M. R. Usman, ''Hydrogen storage methods: Review and current status,'' *Renew. Sustain. Energy Rev.*, vol. 167, Oct. 2022, Art. no. 112743, doi: 10.1016/j.rser.2022.112743.

[384] A. Z. Arsad, M. A. Hannan, A. Q. Al-Shetwi, M. Mansur, K. M. Muttaqi, Z. Y. Dong, and F. Blaabjerg, ''Hydrogen energy storage integrated hybrid renewable energy systems: A review analysis for future research directions,'' *Int. J. Hydrogen Energy*, vol. 47, no. 39, pp. 17285–17312, May 2022, doi: 10.1016/j.ijhydene.2022.03.208.

[385] O. F. Noyan, M. M. Hasan, and N. Pala, ''A global review of the hydrogen energy eco-system,'' *Energies*, vol. 16, no. 3, p. 1484, Feb. 2023, doi: 10.3390/en16031484.

[386] M. A. Mirzaei, A. Sadeghi Yazdankhah, and B. Mohammadi-Ivatloo, ''Stochastic security-constrained operation of wind and hydrogen energy storage systems integrated with price-based demand response,'' *Int. J. Hydrogen Energy*, vol. 44, no. 27, pp. 14217–14227, May 2019, doi: 10.1016/j.ijhydene.2018.12.054.

[387] R. A. Ufa, Y. Y. Malkova, A. L. Gusev, N. Y. Ruban, and A. S. Vasilev, ''Algorithm for optimal pairing of res and hydrogen energy storage systems,'' *Int. J. Hydrogen Energy*, vol. 46, no. 68, pp. 33659–33669, Oct. 2021, doi: 10.1016/j.ijhydene.2021.07.094.

[388] A. M. Elshurafa, A. R. Muhsen, and F. A. Felder, ''Cost, footprint, and reliability implications of deploying hydrogen in off-grid electric vehicle charging stations: A GIS-assisted study for riyadh, Saudi Arabia,'' *Int. J. Hydrogen Energy*, vol. 47, no. 76, pp. 32641–32654, Sep. 2022, doi: 10.1016/j.ijhydene.2022.07.160.

[389] L. Weiming, W. Jiekang, C. Jinjian, M. Yunshou, and C. Shengyu, ''Capacity allocation optimization framework for hydrogen integrated energy system considering hydrogen trading and long-term hydrogen storage,'' *IEEE Access*, vol. 11, pp. 15772–15787, 2023, doi: 10.1109/ACCESS.2022.3228014.

[390] Z. Shao, X. Cao, Q. Zhai, and X. Guan, ''Risk-constrained planning of rural-area hydrogen-based microgrid considering multiscale and multi-energy storage systems,'' *Appl. Energy*, vol. 334, Mar. 2023, Art. no. 120682, doi: 10.1016/j.apenergy.2023.120682.

[391] R. A. Ufa, Y. Y. Malkova, Y. D. Bay, and A. V. Kievets, ''Analysis of the problem of optimal placement and capacity of the hydrogen energy storage system in the power system,'' *Int. J. Hydrogen Energy*, vol. 48, no. 12, pp. 4665–4675, Feb. 2023, doi: 10.1016/j.ijhydene.2022.10.221.

[392] A. Najafi, O. Homaee, M. Jasiński, G. Tsaousoglou, and Z. Leonowicz, ''Integrating hydrogen technology into active distribution networks: The case of private hydrogen refueling stations,'' *Energy*, vol. 278, Sep. 2023, Art. no. 127939, doi: 10.1016/j.energy.2023.127939.

[393] A. Albert and R. Rajagopal, ''Smart meter driven segmentation: What your consumption says about you,'' *IEEE Trans. Power Syst.*, vol. 28, no. 4, pp. 4019–4030, Nov. 2013, doi: 10.1109/TPWRS.2013.2266122.

[394] S. Selvakkumaran, L. Eriksson, and I.-L. Svensson, ''How do business models for prosumers in the district energy sector capture flexibility?'' *Energy Rep.*, vol. 7, pp. 203–212, Oct. 2021, doi: 10.1016/j.egyr.2021.08.154.

[395] W. Yang, W. Liu, C. Y. Chung, and F. Wen, ''Coordinated planning strategy for integrated energy systems in a district energy sector,'' *IEEE Trans. Sustain. Energy*, vol. 11, no. 3, pp. 1807–1819, Jul. 2020, doi: 10.1109/TSTE.2019.2941418.

[396] C. Schick, N. Klempp, and K. Hufendiek, ''Role and impact of prosumers in a sector-integrated energy system with high renewable shares,'' *IEEE Trans. Power Syst.*, vol. 37, no. 4, pp. 3286–3298, Jul. 2022, doi: 10.1109/TPWRS.2020.3040654.

[397] L. Yun, M. Xiao, and L. Li, ''Vehicle-to-manufacturing (V2M) system: A novel approach to improve energy demand flexibility for demand response towards sustainable manufacturing,'' *Appl. Energy*, vol. 323, Oct. 2022, Art. no. 119552, doi: 10.1016/j.apenergy.2022.119552.

[398] Y. Lu, M. Fu, J. Gao, Q. Shi, and W. Liu, ''Voltage limit violation risk evaluation method considering communication failures in distributed voltage regulation system,'' *Int. J. Electr. Power Energy Syst.*, vol. 147, May 2023, Art. no. 108886, doi: 10.1016/j.ijepes.2022.108886.

[399] A. Burgio, D. Cimmino, A. Nappo, L. Smarrazzo, and G. Donatiello, "An IoT-based solution for monitoring and controlling battery energy storage systems at residential and commercial levels," *Energies*, vol. 16, no. 7, p. 3140, Mar. 2023, doi: 10.3390/en16073140.

[400] W. Chen, L. Zheng, H. Li, and X. Pei, "An assessment method for the impact of electric vehicle participation in V2G on the voltage quality of the distribution network," *Energies*, vol. 2022, no. 11, p. 4170, Jun. 2022, doi: 10.3390/EN15114170.

[401] S. Hossain, M. Rokonuzzaman, K. S. Rahman, A. K. M. A. Habib, W.-S. Tan, M. Mahmud, S. Chowdhury, and S. Channumsin, "Grid-vehicle-grid (G2V2G) efficient power transmission: An overview of concept, operations, benefits, concerns, and future challenges," *Sustainability*, vol. 15, no. 7, p. 5782, Mar. 2023, doi: 10.3390/su15075782.

[402] A. Ali, H. H. H. Mousa, M. F. Shaaban, M. A. Azzouz, and A. S. A. Awad, "A comprehensive review on charging topologies and power electronic converter solutions for electric vehicles," *J. Mod. Power Syst. Clean Energy*, vol. 2023, pp. 1–16, Aug. 2023.

[403] M. Ahrarinouri, M. Rastegar, K. Karami, and A. R. Seifi, "Distributed reinforcement learning energy management approach in multiple residential energy hubs," *Sustain. Energy, Grids Netw.*, vol. 32, Dec. 2022, Art. no. 100795, doi: 10.1016/j.segan.2022.100795.

[404] A. E. Avila-Rojas, P. M. De Oliveira-De Jesus, and M. Alvarez, "Distribution network electric vehicle hosting capacity enhancement using an optimal power flow formulation," *Electr. Eng.*, vol. 104, no. 3, pp. 1337–1348, Jun. 2022, doi: 10.1007/S00202-021-01374-7.

[405] Z. Xi, Y. Xiang, Y. Huang, B. Yu, L. Weng, C. Tang, W. Xu, and J. Liu, "Hosting capability assessment and enhancement of electric vehicles in electricity distribution networks," *J. Cleaner Prod.*, vol. 398, Apr. 2023, Art. no. 136638, doi: 10.1016/j.jclepro.2023.136638.

[406] H. Y. Ahmed, Z. M. Ali, M. M. Refaat, and S. H. E. A. Aleem, "A multi-objective planning strategy for electric vehicle charging stations towards low carbon-oriented modern power systems," *Sustainability*, vol. 15, no. 3, p. 2819, Feb. 2023, doi: 10.3390/su15032819.

[407] E. Kazemi-Robati, M. S. Sepasian, H. Hafezi, and H. Arasteh, "PV-hosting-capacity enhancement and power-quality improvement through multiobjective reconfiguration of harmonic-polluted distribution systems," *Int. J. Electr. Power Energy Syst.*, vol. 140, Sep. 2022, Art. no. 107972, doi: 10.1016/j.ijepes.2022.107972.

[408] J. Tian, L. Yu, R. Xue, S. Zhuang, and Y. Shan, "Global low-carbon energy transition in the post-COVID-19 era," *Appl. Energy*, vol. 307, Feb. 2022, Art. no. 118205, doi: 10.1016/j.apenergy.2021.118205.

[409] *Energy Transition—Wikipedia*. Accessed: Jul. 29, 2023. [Online]. Available: https://en.wikipedia.org/wiki/Energy_transition

[410] L. Montero, A. Bello, and J. Reneses, "A review on the unit commitment problem: Approaches, techniques, and resolution methods," *Energies*, vol. 15, no. 4, p. 1296, Feb. 2022, doi: 10.3390/en15041296.

[411] A. Sayed, M. Ebeed, Z. M. Ali, A. B. Abdel-Rahman, M. Ahmed, S. H. E. A. Aleem, A. El-Shahat, and M. Rihan, "A hybrid optimization algorithm for solving of the unit commitment problem considering uncertainty of the load demand," *Energies*, vol. 14, no. 23, p. 8014, Nov. 2021, doi: 10.3390/en14238014.

[412] M. Abujubbeh and B. Natarajan, "Overview of loss sensitivity analysis in modern distribution systems," *IEEE Access*, vol. 10, pp. 16037–16051, 2022, doi: 10.1109/ACCESS.2022.3149481.

[413] B. Tan, J. Zhao, M. Netto, V. Krishnan, V. Terzija, and Y. Zhang, "Power system inertia estimation: Review of methods and the impacts of converter-interfaced generations," *Int. J. Electr. Power Energy Syst.*, vol. 134, Jan. 2022, Art. no. 107362, doi: 10.1016/j.ijepes.2021.107362.

[414] B. Appasani, A. V. Jha, S. K. Mishra, and A. N. Ghazali, "Communication infrastructure for situational awareness enhancement in WAMS with optimal PMU placement," *Prot. Control Mod. Power Syst.*, vol. 6, no. 1, pp. 1–12, Dec. 2021, doi: 10.1186/S41601-021-00189-9.

[415] K. Demertzis, K. Tsiknas, D. Taketzis, D. N. Skoutas, C. Skianis, L. Iliadis, and K. E. Zoiros, "Communication network standards for smart grid infrastructures," *Network*, vol. 1, no. 2, pp. 132–145, Aug. 2021, doi: 10.3390/network1020009.

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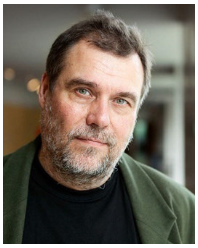

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