中国光储直柔建筑发展战略路径研究

(二期)

Research on the Strategic Path of PEDF Buildings in China (Phase II)

子课题 7：光储直柔相关标准协同性研究

Task 7: Study on the Coordination of PEDF Related Standards

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执行摘要

1. 光储直柔建筑发展初具成效

- **节能减碳效益显著。**在建筑高度电气化情景下，光储直柔建筑运行阶段减碳幅度将超过 60%。除直接减碳效益外，光储直柔建筑对电网供需平衡的调节能力，能让建筑红线以外的间接碳排放减排效果落到实处，具备有效、高比例消纳可再生电力的能力，1 万平方米光储直柔建筑搭配 50 辆电动车，可以消纳 1MW 风电或光电。

- **相关政策已列入各级政府日程。**从国务院到地方省市，已有近 20 个省份将发展建筑"光储直柔"技术列入碳达峰实施方案，鼓励建设新型建筑配电系统，带动建筑实现高质量发展，推动电力电子和消费型家电产业升级，从消费侧推动能源结构调整，对于在全社会层面实现低碳协同发展具有显著的经济和社会效益。

- **光储直柔工程案例开始涌现。**根据中国建筑节能协会光储直柔专委会统计，至 2022 年底我国已经建成和在建的具备光储直柔特征的示范建筑 60 余栋，应用面积约 110 万平方米。多分布于经济较好的珠三角、长三角、北京、上海等地区。其中，广东省主要因为粤港澳大湾区的低碳发展方针为光储直柔项目落地带来了更多政策支持；北京和江苏省也是光储直柔项目试点的先驱，包括研究性质实验楼和技术试点示范；山西省在乡镇与农村光储直柔技术应用方面走在前列，部分农村项目已具有 MW 规模。此外，湖北、江西、贵州省也已有相应示范，意味着光储直柔技术作为重点发展的低碳路径获得了更多的地方政府认可与支持，在"双碳"目标背景下成为了未来关键能源转型应用技术之一。

2. 光储直柔相关现行标准情况

- 由于"光储直柔"2021 年 10 月才正式提出，现行标准中并无光储直柔集成应用的相关规范。而通过梳理光储直柔各分项技术现行标准，可以发现主要以推荐性的技术标准、设计标准、评价标准为主。

- **建筑光伏标准体系相对完善，基本满足工程应用需求。**但重注“装”而不重“用”，缺乏对于建筑自身光伏发电的消纳指引与要求，且行业对“最佳倾角”的概念与“建筑一体化”的过度关注，反而阻碍了建筑师们对光伏的接纳。
- **储能相关现行标准主要以储能电站适用规范与指导文件为主，缺乏建筑储能/用户侧储能应用标准。**这一现状或将随着未来《用户侧电化学储能系统接入配电网技术规定》的发布而有所改善。但是，仍旧缺乏储能“进楼”、电动车“进楼”的技术要求与规范。
- **直流相关现行标准以电力系统中低压直流应用为主，缺乏系统配用电标准，如直流配电设计标准、直流产品标准等。**2022 年 1 月首部《民用建筑直流配电设计标准》T/CABEE 030-2022 发布实施，对指导建筑直流配电系统设计提供了标准支撑。2023 年该标准启动修订，以前在更多工程实践中进一步明确或完善标准，修订内容包括负荷分级和柔性调节（设备功率调节下限）、电压等级与波动识别、光伏自用率及提升以及光储直柔动态计算等；而对于直流产品，除 2023 年 9 月发布的国家标准《家用和类似用途直流插头插座 第 1 部分：通用要求》（GB/T 42710.1-2023）和《家用和类似用途直流插头插座 第 2 部分：型式尺寸》（GB/T 42710.2-2023），非常缺乏直流产品标准，同时对于建筑直流配电如何更好地与建筑电气设计标准衔接缺乏指引。
- **柔性用电相关现行标准以需求响应和并网技术要求为主，缺乏负荷侧柔性用电相关标准，且缺乏对于用电设备参与柔性调节的标准支撑。**目前，团体标准《建筑光储直柔系统评价标准》（T/CABEE 055-2023）对光储直柔整体性能、尤其是柔性提出评价指标和检测方法。直流家电柔性用能评价、直流家电柔性控制测试规范、建筑用电系统柔性量化方法等内容的标准也以纳入“十四五”国家重点研发计划项目立项计划中，预期在 3~5 年内柔性相关标准体系将初步构建。

分类	现有标准体系中存在的问题
建筑光伏	① 重注“装”不重“用”，如何自用？如何最大效益？（补贴退坡时代） ② “最佳倾角”的概念与“建筑一体化”纠结
建筑储能	③ 有储能电站标准，无“进楼”标准 ④ 有电动车及车载电池标准，无“进楼”标准
直流配电	⑤ 有工程建设标准，缺产品标准 ⑥ 如何更好地与建筑电气设计标准衔接
柔性用电	⑦ 有可调节电源标准，无负荷侧柔性用电调节标准 ⑧ 负荷侧有理论，缺用电设备标准支撑
综合	⑨ 国标强制性为主导背景下，如何让标准“掷地有声” ⑩ 牵头部门主管部门之间如何协同，减少边缘地带，如储能进楼、电动车双向、柔性用电等（涉及工信、能源、建设、电力等）

3. 光储直柔相关标准共性技术问题

- **术语和符号。**光储直柔相关标准不仅涉及建筑、机电、暖通等专业，也涉及电力电子、电力工程、能源经济，甚至金融等学科。与光储直柔技术相关的术语和符号等在不同专业及应用领域内可能存在差异，因此，规范与之相关的术语和符号、参数定义等，对于推动光储直柔技术应用将有重要意义。如光储直柔、建筑电气化率、功率主动响应、建筑电网取电率等。

- **电压等级。**直流系统的电压和功率之间存在直接的耦合作用，直流系统可以通过主动调节直流电压实现一些特定的控制目标，即使在正常情况下，直流系统的电压也会在一定范围内变化。对于一个允许各类设备灵活接入的直流系统，不论用哪种方式表示直流电压等级，都必须明确直流电压的变化范围。对工程设计标准，建议采用额定电压表示直流系统电压等级。同时，为了体现直流系统电压特质，建议标准中涉及电压范围的条款均明确具体数值与范围。例如表述为采用额定电压为 750V 的直流配电系统，电压范围为 640V~800V；额定电压为 375V 的直流配电系统，电压范围为 320V~400V。

- **电气设备与配件的通用化模块化。**①变换器：与光储直柔系统直流母线的关系比较密切，不仅直流系统电能质量问题可能造成变换器异常，变换器的一些异常或故障状态也可能影响直流系统的正常运行，为此，需要明确变换器的正常运行条件范围，对变换器的控制和保护功能作出必要的规定，对变换器耐受常见异常的能力作出要求；②安全与保护设备：从电击防护、故障保护和检修维护的角度考虑，要求直流母线与设备之间设置隔离电器，以便在需要时可以将两者可靠断开。断路器兼具过流保护和电气隔离功能，简单实用，在直流配电系统中具有很好的应用前景。由于直流电弧与交流电弧存在较大差异，直流配电系统中的断路器要求采用具备直流灭弧功能的直流断路器。
- **负荷柔性的量化。**光储直柔建筑的“柔性”有多大，也就是其对电力供需平衡的调节潜力有多大，对建立以零碳电力为基础的新型电力系统可以起多大作用。建筑负荷调节能力的实施目的是在满足建筑使用功能的前提下，削减高峰时段负荷，降低建筑用电负荷波动，进而支撑电网供电负荷曲线平滑，帮助电网实现更加灵活、韧性、经济的供电。其能力的量化，即建筑光储直柔系统柔性效果评价包括单次调节能力评价和全天 24h 连续调节能力评价，主要包括调节深度、持续时间、调节成本等三要素。

4. 光储直柔标准体系内外协同

- **逐步开展与光储直柔技术相关制/修订标准的协同，以及与强制性标准的协同。**光储直柔作为仍处于起步示范阶段的新技术，究其工程应用也不过近五年时间，很多早已发布的现行国家标准、行业标准并无针对光储直柔应用或已不适用于当下光储直柔技术的相关要求。因此，逐步从正在编制或修订的标准开展与光储直柔技术内容的协同性研究，对推动光储直柔规模化发展具有重要支撑意义。尤其是当前正处于国家标准化改革过程中，仅区分强制性标准和推荐性标准，与强制性标准的协同，将对光储直柔的推广应用至关重要。

- **光储直柔相关技术纳入绿色建筑、零碳建筑、绿色低碳社区等 7 项现行或已有建筑节能与绿色建筑相关标准体系。**新设与建筑电力交互、负荷调节等相关的术语与条文，并作为加分项纳入《绿色建筑评价标准》GB/T50378 局部修订征求意见稿中，以此来鼓励和引导建筑采用光储直柔技术，实现建筑电力交互。同时，根据光储直柔研究成果与既有工程实践经验，将光储直柔技术纳入近零碳建筑、零碳建筑判定，并写入国家标准《零碳建筑技术标准》征求意见稿中。

- **建筑直流配电系统纳入 7 项相关节能设计标准中电气设计或新型供配电专项。**从节能设计整体角度看，不仅要关注建筑用电需求侧，还需要关注高比例可再生电力供给侧，以及二者共同构建的新型电力系统。这也是光储直柔与建筑节能设计标准之间需要协同的关键点。建筑节能应从重视节能（节约 kWh）向重视柔性（调节 kW）转变。节能和柔性是对立统一的，二者目标一致，互相转换。当节能很差时，柔性不能解决问题，节能是主要任务；当节能做到一定程度后，柔性转为矛盾的主要方面。二者关系还与能源结构有关：当化石能源电力为主时，任何时候的电量都是高成本，因此节能为主；当可再生零碳电力比例加大后，火电成为调峰手段，柔性就转为主要矛盾。

- **建筑电力交互、负荷柔性纳入碳中和建筑相关标准。**建筑依靠分布式能源、储能、直流配电及柔性用电，通过响应电网信号调整用能负荷，可以将建筑用能需求从电网需求高峰时期转移到供给高峰时期，从而帮助电网实现峰值平滑，这是电网交互技术的基本原理。基于此技术建设的高能效建筑，在国内被称为建筑电力交互（Grid Interactive Building，简称 GIB），在国外又被称为电网交互高能效建筑（Grid-interactive efficient buildings，简称 GEB）。GIB 或 GEB 的研究和实践方兴未艾，在我国的主要应用形式是直流建筑。衡量建筑电力交互能力的直接指标是建筑负荷调节比例，设置建筑负荷调节能力、建筑电气化率相关条文，纳入《碳中和建筑评价标准》征求意见稿。

标准修订协同	标准制订协同	强制性标准协同
① GB 51348-2019《民用建筑电气设计标准》 **② GB/T 50378-2019《绿色建筑评价标准》** **③ GB/T 51141-2015《既有建筑绿色改造评价标准》** **④ GB/T 50801-2013《可再生能源建筑应用工程评价标准》** **⑤ GB/T 50189-2015《公共建筑节能设计标准》** **⑥ 北京市 DB11/687-2015《公共建筑节能设计标准》** **⑦ 中国建筑节能协会标准 T/CABEE 030-2022《民用建筑直流配电设计标准》**	① 国家标准《零碳建筑技术标准》 ② 深圳市地方标准《零碳建筑评价标准》 ③ 深圳市地方标准《建筑光储直柔技术规程》 ④ DB1331/T037-2023《雄安新区绿色低碳社区评价标准》 ⑤ 中国标准化协会标准《碳中和建筑评价标准》 ⑥ 中国标准化协会标准《建筑空调负荷柔性调节性能评价标准》 ⑦ 中国标准化协会标准《公共建筑电力需求侧管理系统技术规程》 ⑧ 中国建筑节能协会标准《建筑电化学储能技术规程》 ⑨ T/CABEE 055-2023《建筑光储直柔系统评价标准》 ⑩ 中国建筑节能协会标准《建筑光储直柔系统变换器通用技术标准》 ⑪ 国标图集《建筑用太阳能构件一体化设计与安装》 ⑫ 四川省建筑标准设计图集《建筑光储直柔系统设计及安装标准图集》	① 强制性国标《太阳能发电工程项目规范》 ② 强制性国标《电动汽车充换电设施项目规范》

5. 光储直柔相关标准协同存在的问题及应对措施

- **建立建筑直流配电用产品标准，插头插座已发布，直流终端电器和直流配电设备相关产品标准已完成关键技术科技项目立项。**2023 年 9 月发布的直流插头插座标准为：国家标准《家用和类似用途直流插头插座 第 1 部分：通用要求》（GB/T 42710.1-2023）、《家用和类似用途直流插

头插座 第 2 部分：型式尺寸》（GB/T 42710.2-2023）。而直流终端电器标准将基于“十四五”国家重点研发计划 2022 年度项目“建筑机电设备直流化产品研制与示范”开展研究，直流配电系统相关标准也在 2023 年度完成“十四五”国家重点研发计划指南发布，正在申报中。

- **完善直流配电和光储直柔系统标准，启动八个专题深入研究，完成深圳光储直柔地标等标准立项，进一步加强光储直柔相关技术标准化，最大化实现“柔”的价值。**通过梳理了与“光储直柔”四项技术相关的 244 项标准，分析了光储直柔当前应用存在的问题。光储直柔诠释了工程的表象与内在，或者说是兼顾了工程的过程和结果。从字面上就阐释了新型建筑供配电系统的组成，使我们清楚地认识到工程元素的构成，但恰恰是看不见摸不着的“柔”体现了其工程价值。传统思维下仅关注工程上“有没有”、“用没用”，鲜少关注用得结果“好不好”。光储直柔相关标准应以柔性为导向，重点关注系统性能。2023 年 8 月底，深圳市地方标准《建筑光储直柔工程技术规程》启动立项，将进一步推动光储直柔建筑规模化应用。

- **推动直流配用电标准国标化，转化的契机已现。**2023 年 8 月，国家标准化管理委员会发布《推荐性国家标准采信团体标准暂行规定》，并于发布之日起施行。可将技术内容具有先进性、引领性、实施满 2 年且实施效果良好的团体标准，采信为推荐性国家标准。这将成为当前已发布或制订中的直流配用电相关标准国标化的重要契机。同时，国家标准委等十一部门联合印发《碳达峰碳中和标准体系建设指南》也将对制订光储直柔建筑直流配用电标准起到重要推动作用。

- **建立建筑与电力领域技术和标准化沟通机制，共同推动国家碳达峰碳中和标准化提升行动计划及标准体系建设。**光储直柔是多学科、多领域、多行业融合的必然结果。不仅涉及建筑、机电、暖通等专业，也涉及电力电子、电力工程、能源经济，甚至金融等学科，对于推动新能源、数字经济、绿色消费等多领域的快速发展，以及建筑、电力、交通多行业能源结构的转型具有重要的作用。光储直相关标准体系建设将推动相

关标准完善和跨行业标准协同，加强技术标准的顶层设计和编制协调，重点推进支撑工程实施、技术评价，以及直流接口和用电电器的系列化标准，为“光储直柔”技术的推广提供全面有力的支撑。未来，随着光储直柔理论研究与工程实践的开展，与之相关的标准体系将逐渐完善。光储直柔核心目标在“柔”，即柔性用电，负荷调节等相关标准制订已纳入国家碳达峰碳中和标准化提升行动计划及标准体系建设指南中，进一步促进发挥标准推动能源绿色低碳转型的技术支撑和引领性作用。

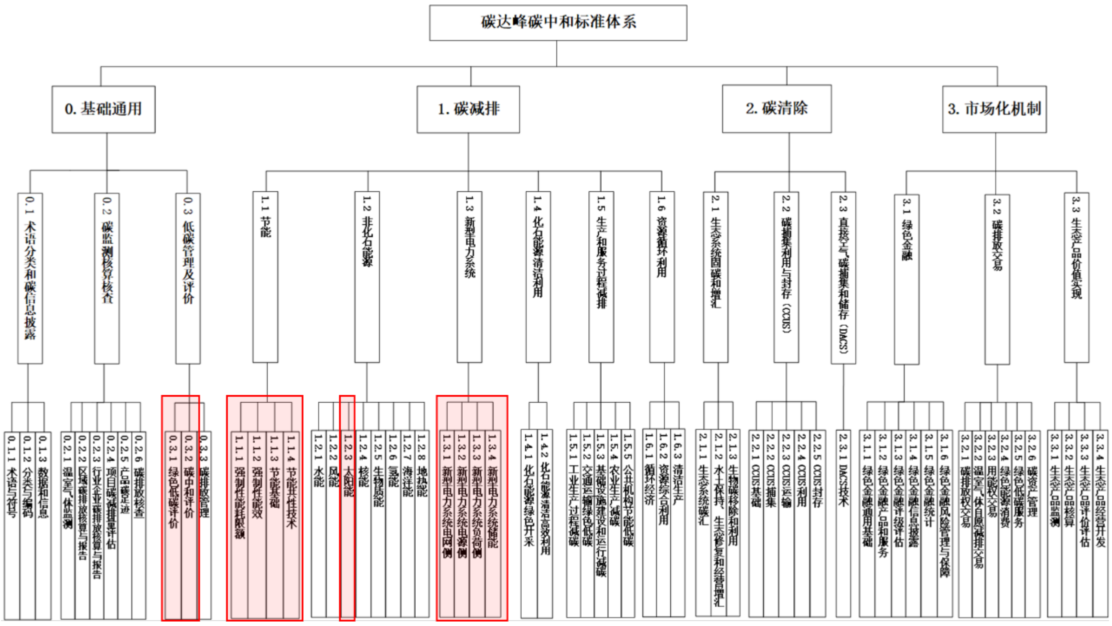

图 1 碳达峰碳中和标准体系

Executive Summary

1. Significant Progress in the Development of PEDF Buildings

- **Remarkable Benefits in Energy Conservation and Carbon Reduction:** In the context of highly electrified buildings, PEDF buildings have demonstrated carbon reduction capabilities exceeding 60% during their operational phase. In addition to direct carbon reduction benefits, the ability of PEDF buildings to adjust the supply and demand balance of the grid can make indirect carbon emission reduction effects outside the building line come into effect. Moreover, PEDF buildings excel at absorbing and utilizing high levels of renewable energy. For example, a 10,000 m^2 PEDF building equipped with 50 electric vehicles can consume up to 1 MW of wind or solar energy.

- **Inclusion in Government Agendas at Various Levels:** From the State Council to local provincial governments, nearly 20 provinces have included the development of PEDF technology and the construction of new types of building power distribution systems. These initiatives are being prioritized to stimulate high-quality growth in the construction sector, and also aim to promote the power electronics and household appliance industries, ultimately shifting energy consumption patterns to a more sustainable model from the consumption side. The economic and social benefits of these steps are significant, especially in achieving collaborative low-carbon development across society.

- **Emergence of PEDF Project Case Studies:** According to statistics from the Photovoltaic, Energy Storage, Direct Current, Flexible (PEDF) Committee of the China Association of Building Energy Efficiency (CABEE), by the end of 2022, China had completed and had under construction more than 60 demonstration buildings featuring PEDF, covering an area of approximately

1.1 million square meters. These buildings are primarily located in economically developed areas such as the Pearl River Delta, Yangtze River Delta, Beijing, and Shanghai. Guangdong Province, in particular, has received additional policy support for PEDF projects due to the low-carbon development policy of the Guangdong-Hong Kong-Macao Greater Bay Area. Beijing and Jiangsu Province have pioneered PEDF pilot projects, including experimental research buildings and technological demonstrations. Shanxi Province leads in the application of PEDF technology in townships and rural areas, with some rural projects reaching MW scale. In addition, Hubei, Jiangxi and Guizhou provinces have also begun to showcase examples, indicating broader local government recognition and support for PEDF technology as a key low-carbon development pathway and one of the key application technologies for future energy transformation, especially in the context of China's "dual carbon" goals.

2. Current State of Relevant Standards for PEDF

- Since the concept of "PEDF" was officially proposed in October 2021, there have been no existing standards specifically focused on the integrated application of PEDF. A review of the existing standards for each sub-technology under PEDF shows that they are mainly consist of recommended technical standards, design standards, and assessment standards.

- **Standards for Building Photovoltaics (PV) Are Well-Established:** The current system of building PV standards are relatively comprehensive and largely meets the needs of engineering applications. However, there is an overemphasis on installation over utility, with insufficient guidance and requirements for building self-consumption of the PV energy generated. In addition, the industry's focus on the "optimal angle" concept and "building integrated photovoltaic" ironically hinders the adoption of PV by architects.

- **Gaps in Current Energy Storage Standards for Building and Customer-**

Side Applications: Current energy storage standards focus primarily on norms and guidelines for energy storage stations, leaving a gap in the standards for building energy storage and customer-side energy storage applications. This situation may be improved with the upcoming publication of the *Technical Regulations for the Connection of Customer-side Electrochemical Energy Storage Systems to the Distribution Grid*. However, there is still a lack of technical requirements and norms for bringing energy storage systems "into buildings" and electric vehicles "into buildings."

- **The current standards related to direct current (DC) mainly focus on low-voltage DC applications in power systems, lacking system standards for DC distribution design and DC product standards:** In January 2022, the first *Design Standard for Direct Current Power Distribution of Civil Buildings* (T/CABEE 030-2022) was published and implemented, providing standard support for guiding the design of DC distribution systems in buildings. In 2023, the revision of this standard was initiated to further clarify or improve the standards based on more engineering practices. The revision includes load grading and flexible adjustment (lower limit of equipment power adjustment), voltage level and fluctuation identification, photovoltaic self-consumption rate and improvement, and dynamic calculation of photovoltaic energy storage and flexibility. As for DC products, although new national standards were published in September 2023, namely the *Plugs and Socket-Outlets for Household and Similar Purposes – Part 1: General Requirements* (GB/T 42710.1-2023) and the *Plugs and Socket-Outlets for Household and Similar Purposes – Part 2: Types and Dimensions (*GB/T 42710.2-2023*)*, there is still a glaring lack of DC product standards. In addition, there is a lack of guidance on how to better integrate DC building distribution with building electrical design standards.

- **Standards for Flexible Electricity Usage Are Incomplete:** Existing standards in this area primarily address demand response and grid connection requirements, and lack standards related to flexible electricity use on the load side and support for electrical devices participating in flexible adjustments. A group standard is currently released, *Assessment standard for Photovoltaics, Energy storage, Direct current and Flexibility(PEDF) system in buildings* (T/CABEE 055-2023), which aims to establish assessment metrics and testing methods for overall PEDF performance, particularly in the area of flexibility. Standards covering topics such as DC household appliance flexibility assessment, DC household appliance flexibility control test criteria, and building electrical system flexibility quantification methods are also being included in the 14th Five-Year National Key R&D Program, with the expectation that a preliminary framework for flexibility-related standards will be established within the next 3 to 5 years.

Table 1 Existing Issues in the Current Standard System

Category	Existing Issues in the Current Standard System
Building Photovoltaic (PV)	1) Emphasis on "installation" rather than "use": How to self-consume? How to maximize benefits? (In the era of subsidy decline) 2) Conflict between the concept of "optimal angle" and "building integrated photovoltaic"
Building Energy Storage	3) Standards exist for energy storage stations but none for "indoor integration" 4) Standards exist for electric vehicles and vehicle batteries, but none for "indoor integration"
DC Distribution	5) Standards exist for construction but none for products 6) How to better integrate with building electrical design standards
Flexible Electricity Use	7) Standards exist for adjustable power supply but none for load-side flexible electricity use adjustments 8) Theoretical support exists on the load side, but lacks standard support for electrical equipment
Comprehensive	9) How to make standards effective in a context dominated by mandatory national standards 10) How to coordinate among leading and competent departments to reduce marginal areas, such as indoor energy storage integration, bidirectional electric vehicles, flexible electricity use, etc. (involving industrial information, energy, construction, electricity, etc.)

3. Common Technical Issues in PEDF-related Standards

- **Terminology and Symbols.** Standards related to PEDF not only cover multiple disciplines such as building science, mechanical and electrical engineering, and HVAC, but also include disciplines such as power electronics, electrical engineering, energy economics, and even finance. There may be variations in the terminology and symbols associated with PEDF technologies across different disciplines and applications. Therefore, standardization of the terminology, symbols, and parameter definitions associated with these technologies is of significant importance in advancing the application of PEDF technologies. This includes terms such as PEDF, building electrification rate, active power response, and building grid consumption rate.

- **Voltage Levels.** In DC systems, voltage and power are intrinsically linked, allowing for active voltage adjustment to achieve specific control objectives. Even under standard conditions, the voltage of the DC system will fluctuate within a predefined range. For a versatile DC system that can accommodate a variety of equipment, it is essential to explicitly specify the range of voltage fluctuation, regardless of how the voltage levels are labeled. Engineering design standards should adopt the notion of rated voltage to describe the voltage level of the DC system. To accurately capture the unique characteristics of DC voltage, it is recommended that any clauses in the standards that refer to voltage ranges explicitly state the specific values and ranges. For example, for a DC distribution system with a rated voltage of 750V, the voltage range should be explicitly defined as 640V to 800V; for one with a rated voltage of 375V, the range should be 320V to 400V.

- **Standardization and Modularization of Electrical Equipment and Accessories.** 1) Converters: The relationship between converters and the DC bus in PEDF systems is highly integral. Issues related to the quality of electrical energy in DC systems can lead to anomalies in converters, and conversely, faults in converters can disrupt the normal functioning of DC systems. Therefore, it's imperative to clearly define the operating conditions for converters. Regulatory requirements must be established for the control and protection functions of converters and their ability to withstand common abnormal conditions; and 2) Safety and Protection Devices: From the standpoint of electrical shock protection, fault isolation, and maintenance, it is critical to install isolators between the DC bus and the connected equipment that provide reliable disconnection when necessary. Circuit breakers, which serve the dual purpose of overcurrent protection and electrical isolation, are simple, effective, and promising for use in DC distribution systems. Given the significant differences between DC and AC electrical arcs, circuit breakers within DC systems must be equipped with DC arc-extinguishing capabilities.

- **Quantification of Load Flexibility.** The degree of "flexibility" inherent in PEDF buildings speaks volumes about their potential to modulate the balance between electrical supply and demand. This is particularly important when considering their role in spearheading a novel electric power system based on zero-carbon energy. The ultimate goal of incorporating load management capabilities into these structures is to reduce peak power consumption, thereby minimizing the volatility of building energy use. This, in turn, smooths the grid's load curve, enabling a more agile, resilient, and economically efficient power supply. To quantify these capabilities, assessments are typically divided into two distinct but complementary aspects: Single-Instance Adaptability and 24-Hour Continuous Adaptability, which mainly involves three elements: adjustment depth, duration and adjustment cost.

4. Internal and External Synergy in PEDF Standard Systems

- **A phased rollout of synergistic initiatives related to the establishment or**

modification of standards for PEDF technology is essential, including collaboration with mandatory standards. Given that PEDF is a new technology still in the demonstration phase, its practical applications have only been around for about five years. As a result, many existing national and industry standards either don't address the unique needs of PEDF applications or have become obsolete for modern PEDF technology requirements. Therefore, initiating synergistic research with the PEDF technology specifications in current or upcoming standards revisions is critical to fostering the scaled development of PEDF. This is especially relevant at a time when the nation is undergoing standardization reforms that focus only on distinguishing between mandatory and recommended standards. In this context, alignment with mandatory standards is critical to the widespread adoption and application of PEDF technology.

- **Inclusion of PEDF-related technologies in 7 existing or new standards for green buildings, zero-carbon buildings, and low-carbon green communities.** New terms and clauses related to building-grid interaction and load adjustment are added as bonus criteria in the draft for partial revision of the *Green Building Evaluation Standard* (GB/T50378) to promote and guide the adoption of PEDF technologies for building-grid interaction. In addition, based on research findings and existing engineering practices, PEDF technology will be integrated into criteria for near-zero and zero-carbon buildings and included in the draft national standard, the *Zero Carbon Building Technical Standard*.
- **Incorporation of DC building distribution systems into 7 energy-efficient electrical design standards of innovative power supply and distribution specializations.** From a holistic perspective of energy efficient design, the focus should be not only on the demand side of building electricity use, but also on the high proportion of renewable energy supply and the newly constructed power system that both constitute. This is a key point where

synergies between PEDF and building energy efficiency design standards are needed. The pivot should be from an emphasis on energy conservation (saving kWh) to flexibility (adapting kW). Energy savings and flexibility are inherently complementary; when energy efficiency is low, flexibility can't solve the problems and energy conservation becomes the primary goal. However, when energy efficiency reaches a certain point, flexibility takes precedence. Their relationship also varies with the energy mix: when fossil-fueled electricity dominates, energy conservation takes precedence; as the share of renewable, zero-carbon electricity increases, flexibility takes precedence.

- **Inclusion of building-grid interactions and load flexibility into carbon-neutral building-related standards.** Buildings can rely on distributed energy resources, energy storage, DC distribution, and flexible electricity use to adjust energy loads in response to grid signals. This shift of building energy demand from periods of peak grid demand to periods of peak supply helps smooth out grid peaks, following the basic principle of grid interactive technologies. Buildings based on this technology, known domestically as Grid Interactive Buildings (GIB) and internationally as Grid-interactive Efficient Buildings (GEB), are an emerging field. The key indicator to measure such building-grid interaction capabilities is the building load adjustment ratio. Clauses related to this, along with the rate of building electrification, are included in the draft of the *Carbon Neutral Building Evaluation Standard*.

Table 2 List of collaborative standards

Standard Revision Coordination	Standard Formulation Coordination	Mandatory Standard Coordination
1) Standard for Electrical Design of Civil Buildings (GB 51348-2019) **2) Assessment Standard for Green Building (GB/T 50378-2019)**	1) Technical Standard for Zero Carbon Buildings (National Standard 2) Evaluation Method and Criteria for Green Buildings (Shenzhen Local Standard)	1) Solar Power Project Specifications (Mandatory National Standard) 2) Electric Vehicle Charging and Swapping Facilities Project Specifications (Mandatory

3) Assessment Standard for Green Retrofitting of Existing Building (GB/T 51141-2015) **4) Evaluation Standard for Application of Renewable Energy in Buildings (GB/T 50801-2013)** **5) Design Standard for Energy Efficiency of Public Buildings (GB/T 50189-2015)** **6) Design Standard for Energy Efficiency of Public Buildings (Beijing DB11/687-2015)** **7) Design Standard for Direct Current Power Distribution of** **Civil Buildings (China Association of Building Energy Efficiency Standard - T/CABEE 030-2022)**	3) Regulations on Building PEDF Technology (Shenzhen Local Standard) 4) Evaluation Criteria for Xiongan New Area Low-Carbon Green Community (DB1331/T037-2023) 5) Standards for Evaluating Carbon-Neutral Buildings (Standard of China Association for Standardization (CAS)) 6) Performance Evaluation Standards for Building Air-Conditioning Load Flexibility (Standard of China Association for Standardization (CAS)) 7) Technical Regulations for Managing Electric Power Demand in Public Buildings (Standard of China Association for Standardization (CAS)) 8) Technical Regulations for Electrochemical Energy Storage in Buildings (Standard of China Association of Building Energy Efficiency (CABEE)) 9) Assessment standard for Photovoltaics, Energy storage, Direct current and Flexibility(PEDF) system in buildings (T/CABEE 055-2023) 10) Universal Technical Standards for Building PEDF System Inverters (Standard of China Association of Building Energy Efficiency (CABEE)) 11) Solar Components Integrated Design and Installation for Buildings (National Building Standard Design Atlas) 12) Building PEDF System Design and Installation Standard Atlas (Sichuan Provincial Building Standard Design Atlas)	National Standard)

5. Challenges and Countermeasures in Synergizing to PEDF-related

Standards

- **The establishment of product standards for DC power distribution in buildings is progressing. The standards for DC plugs and sockets have already been published, and the standards for DC terminal appliances and DC distribution equipment are underway:** The standards for DC plugs and sockets, released in September 2023, include the *Plugs and Socket-Outlets for Household and Similar Purposes – Part 1: General Requirements* (GB/T 42710.1-2023) and the *Plugs and Socket-Outlets for Household and Similar Purposes – Part 2: Types and Dimensions (*GB/T 42710.2-2023*)*. The standards for DC terminal appliances will be based on the research conducted under the "14th Five-Year" National Key Research and Development Program's 2022 project "Development and Demonstration of DC-based Building Electromechanical Equipment", and the standards for DC distribution systems are also scheduled in the "14th Five-Year" National Key Research and Development Program guidelines for 2023, with the application currently being submitted.
- **To enhance the standards for DC power distribution and PEDF systems, eight in-depth research topics have been initiated. The establishment of standards, such as the Shenzhen Local Standard *Regulations on Building PEDF Technology*, has been initiated to further strengthen the standardization of PEDF technologies and maximize the value of "flexibility" in PEDF standardization:** Through an analysis of 244 standards related to the four technological components of PEDF, we've identified several current challenges in PEDF applications (as shown in Table 1). PEDF embodies both the visible and underlying aspects of engineering processes and outcomes. While it explicitly clarifies the elements of new building power supply systems, it is the intangible aspect of "flexibility" that truly represents its engineering value. Traditional approaches mainly focus on the binary questions of "presence or absence" and "utility or futility" in

engineering, seldom considering the quality of the results. The standards related to PEDF should be guided by flexibility and focus on system performance. At the end of August 2023, the local standard *Technical Regulations for PEDF in Building Engineering* was initiated in Shenzhen, which will further promote the large-scale application of PEDF in buildings.

- **The standardization of DC distribution for power utilization is being promoted, and the opportunity for transformation has emerged：** In August 2023, the National Standardization Administration of China issued the *Interim Provisions on the Adoption of Group Standards as Recommended National Standards*. This provision allows group standards with advanced, leading, and well-implemented technical content that has been implemented for at least 2 years and has shown good results to be adopted as recommended national standards. This will be an important opportunity for the national standardization of DC distribution standards that have already been published or are being developed. Additionally, the joint issuance of the *Guidelines for the Construction of Carbon Peak and Carbon Neutrality Standard System* by eleven departments, including the National Standardization Administration, will also play an important role in promoting the development of DC distribution standards for PEDF in buildings.
- **Establishing communication mechanisms for technical standards in the building and electrical sectors, in order to collectively advance the National Action Plan for Carbon Peak and Carbon Neutrality, as well as the development of the broader standardization framework:** PEDF is the natural outcome of multi-disciplinary, cross-sector and cross-industry integration. It includes not only construction, mechanical and electrical engineering, and HVAC, but also fields like power electronics, electrical engineering, energy economics, and even finance. As such, it plays a critical role in accelerating the growth of various sectors such as new energy, digital economy, and green consumption, as well as the energy transition in construction, electrical, and transportation industries. The development of a

cohesive PEDF standardization framework will enhance standard interoperability across industries and strengthen top-level design and coordinated formulation of technical standards. A focus will be placed on facilitating engineering implementation, technical assessment, and the standardization of DC interfaces and electrical appliances. As the theoretical and practical advancements in PEDF continue to evolve, its related standardization framework will become increasingly comprehensive. The core objective of PEDF lies in "flexibility"—flexible energy utilization and load adjustments. Relevant standard formulation has already been incorporated into the national action plan and guidelines for achieving peak carbon neutrality, thereby serving as a technical pillar and pioneer in promoting a green, low-carbon energy transition.

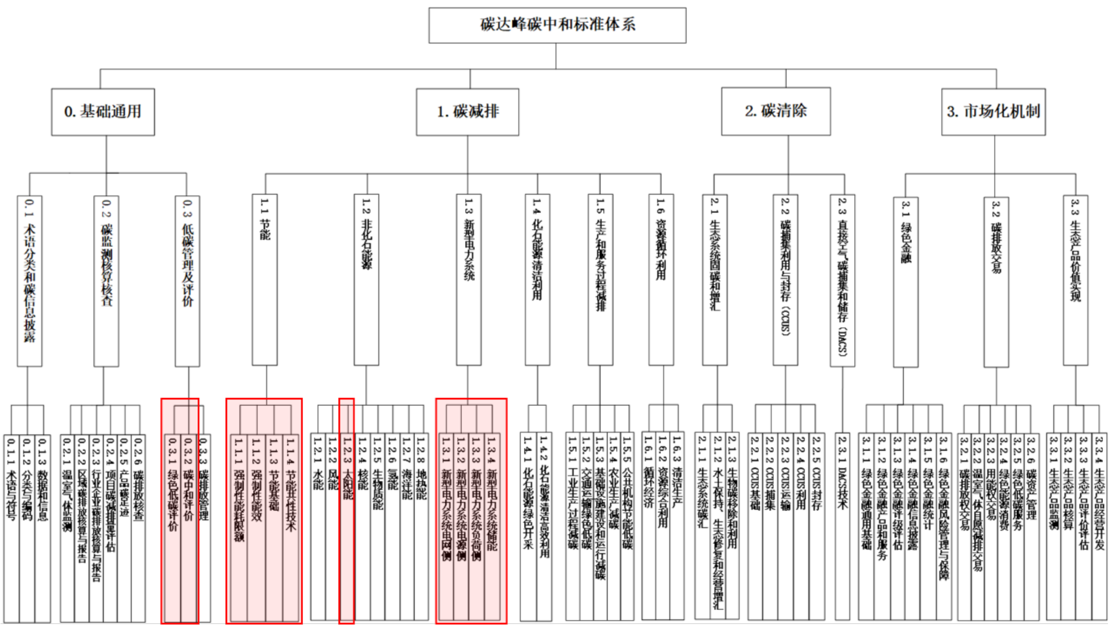

Figure 1 Carbon Peak and Carbon Neutrality Standard System