USAID COLOMBIA YOUNG LEADERS WORKFORCE TRAINING PROGRAM ACTION PLANS: REGULATORY ROAD MAP FOR DISTRIBUTED ENERGY RESOURCE (DER) INTERCONNECTION AND INTEROPERABILITY

INTRODUCTION

As part of the U.S. Agency for International Development[1] (USAID)-National Renewable Energy Laboratory (NREL) Young Leaders Workforce Training Program in Colombia, participants from Colombia's Energy and Gas Regulatory Commission (CREG) leveraged their training and professional experience to develop a regulatory roadmap for the interconnection and interoperability of increasing integration of distributed energy resources (DERs). CREG was one of four teams selected by the training program development team to receive continued technical assistance and strategic advisory support from the USAID-NREL Partnership for action plan development and implementation.

CREG's action plan focused on developing a proposed regulatory roadmap to update Colombia's distribution code for the integration of DERs, including energy storage and electric vehicles, considering the design and development of new markets in the distribution network. As part of the ongoing technical assistance from the USAID-NREL Partnership, strategic advisory support was provided to CREG to develop a new framework for updating interconnection rules, benchmarking against international standards, identifying appropriate policies for different market phases, detailing the types of DERs to consider, assessing the potential for DER grid services, and exploring other technical considerations and requirements. CREG advisors provided NREL with an original action plan and theoretical roadmap that formed the basis for the technical support, including the identification of distribution code updates to be explored further.

BACKGROUND

Electricity systems are rapidly changing as new technologies and innovations like distributed renewable energy, electric vehicles, energy storage, and advanced metering and controls come online with greater penetration into national grids. This change creates key opportunities and challenges for policymakers, regulators, and other stakeholders, as the existing electricity distribution systems, and the business models and structures underpinning them, must be updated to reflect this changing landscape.

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Colombia is an example of a rapidly evolving market for DERs, with distributed generation (e.g., rooftop solar) expected to reach 716 MW by 2035 and over 600,000 electric vehicles expected on the road (and supported by a charging-station network) by 2030. To ensure these resources are safely and reliably integrated, Colombia must update the technical and commercial requirements for its distribution networks.

Colombia's current distribution networks are governed by its distribution code (Resolution CREG 070 of 1998) that establishes the rules for managing and expanding distribution networks. This includes the responsibilities of network operators, technical design criteria, power quality, operational planning and supervision, and specific criteria for supporting/triggering expansion of the networks. The code also establishes criteria for the expansion of distribution systems, namely: (1) meeting demand, (2) adaptability (incorporation of technological advances), (3) flexibility (i.e., inclusion of unforeseen works), (4) environmental viability, (5) standards and permits, (6) economic efficiency, (7) quality and continuity of supply, and (8) coordination with the national interconnected system.

While these guidelines provide a solid foundation, the existing grid code was designed to support traditional electricity generation (e.g., from centralized fossil fuel and hydropower plants) and distribution

1 English: https://www.nrel.gov/docs/fy22osti/82855.pdf; Spanish: https://www.nrel.gov/usaid-partnership/assets/pdfs/nrel-usaid-colombia-brochure-fy22.pdf.

(e.g., power flow in one direction from "high-voltage networks" to "low-voltage networks"). The code specifically does not establish concrete methods to expand the distribution system for the optimal integration of new DER technologies or new types of loads on the distribution system. This highlights a key need to update and clarify the rules to support adoption of DERs and proactively respond to challenges that arise.

When updating and implementing the interconnection rules, key concepts such as power quality, safety, reliability, protection, affordability, and market development, amongst other things, help to define the overarching goals for the technical requirements. After defining the goals and technical requirements, the system regulators also need to determine the associated thresholds and scope for expected updates in the future. This requires the anticipation of frequent updates in an evolving market, as well as an understanding of future coordination needs amongst stakeholders beyond the distribution utility.

OBJECTIVES

The primary objective of the Action Plan technical assistance was for NREL to provide working input in support of CREG's objective to establish the general steps (proposed roadmap) for updating the distribution code for DER integration. This included distributed renewable energy systems, electric vehicles, energy storage systems, and more specifically, the design and development of new markets related to DER integration and interoperability, while improving resilience, flexibility, and observability of the distribution network.

METHODOLOGY

As DER integration can have major implications for the traditional utility business model, NREL drew upon global best practices in evolving regulations for DER integration to share lessons learned, best practices, and benchmarking standards (e.g., International Standard IEEE 1547- 2018), to provide guidance for CREG to consider in their regulatory roadmap development for DER integration. Using a cohort approach, NREL worked with the CREG advisors and key stakeholders to holistically evaluate DER interconnection processes, first defining the broader context and objectives that motivated the regulatory work. Understanding the goals for overall power sector planning and operation is vital when assessing the decision-making process, potential impacts, and implications for DER integration, as shown in **Figure 1**.

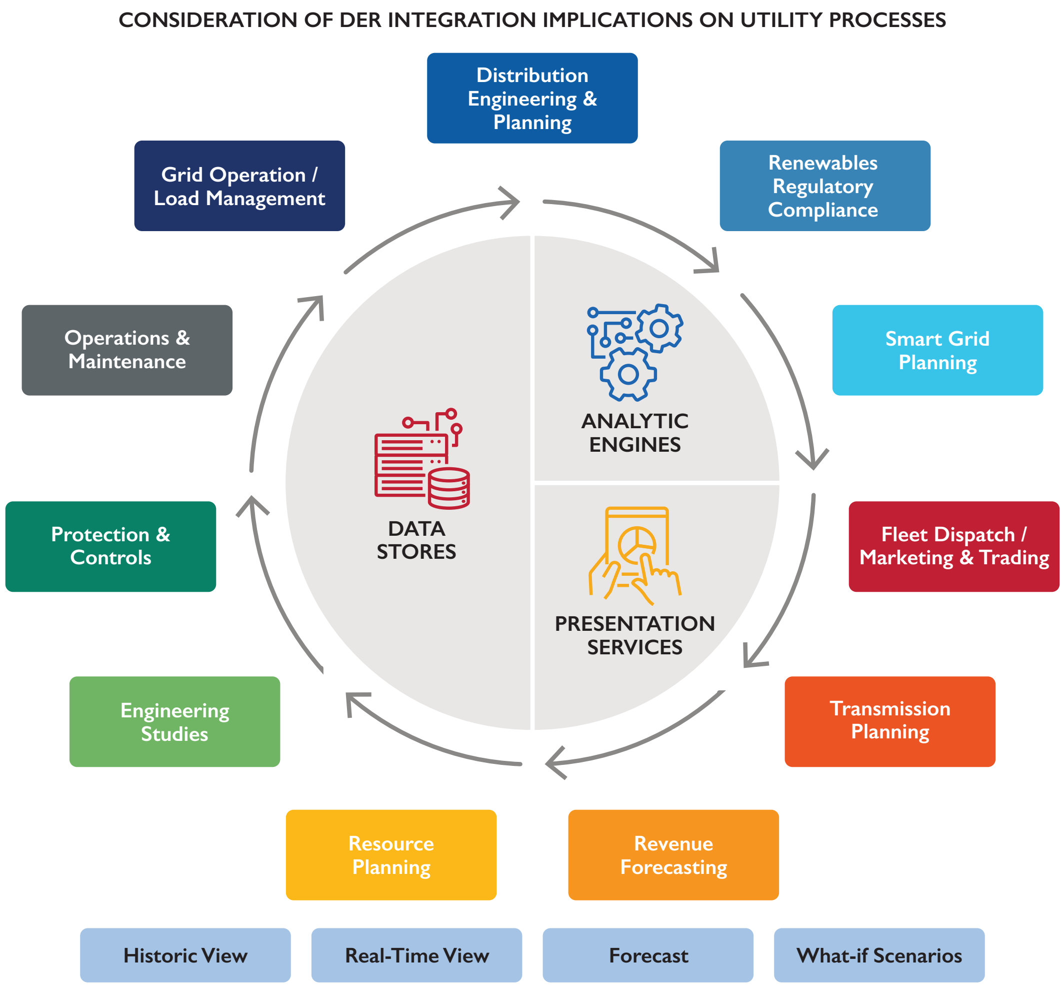

Figure 1. Example considerations of DER integration implications on electric utility processes

ROLES & RESPONSIBILITIES

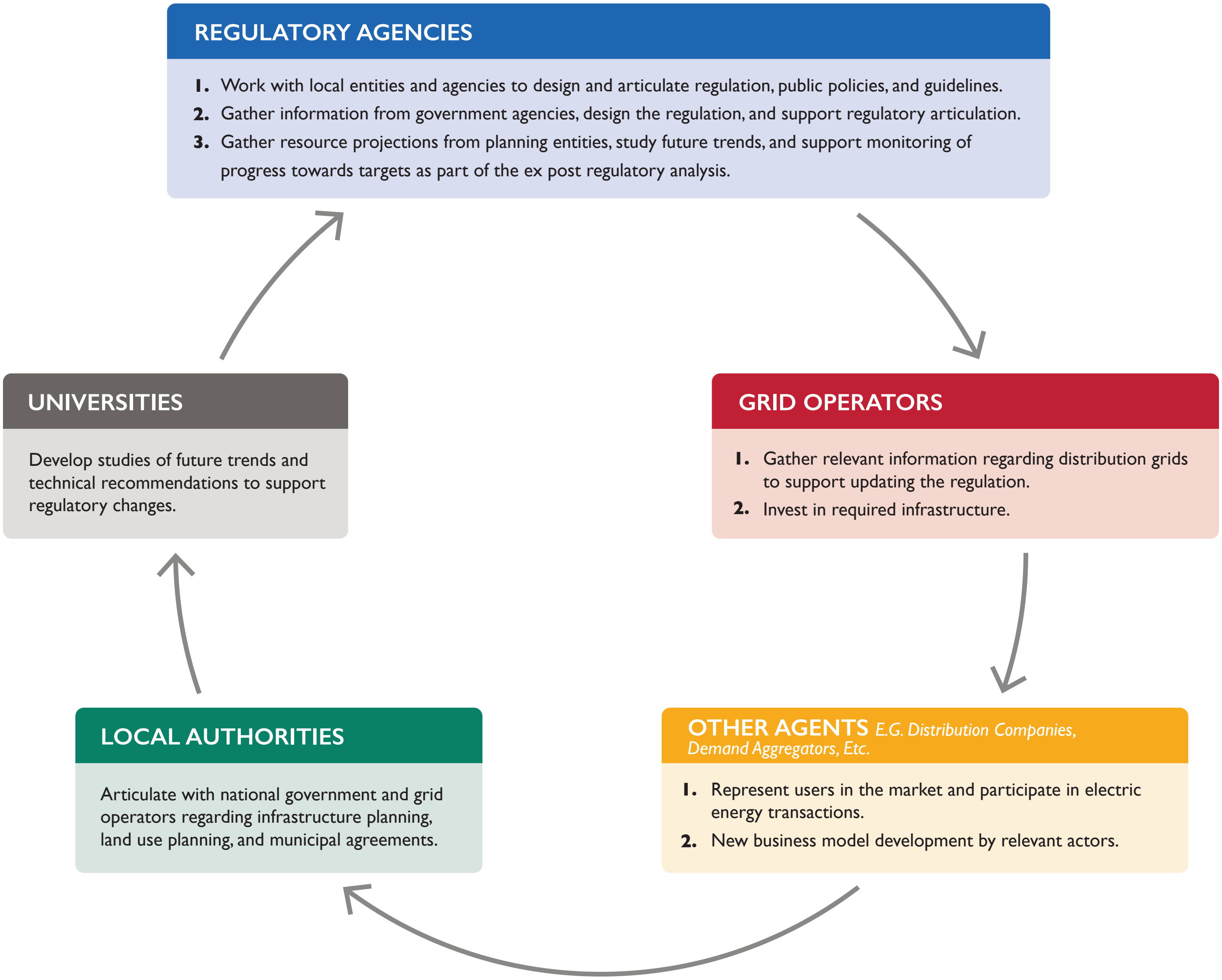

Figure 2. Roles and responsibilities for DER integration

To better anticipate stakeholder coordination and differentiated roles in the regulatory roadmap, clear delineation between the roles and responsibilities of relevant jurisdictional authorities, such as utilities, regulators, and other stakeholders, is needed to address their changing responsibilities as new challenges arise and new technologies enter the system. To achieve this, CREG advisors, NREL, Colombia's Ministry of Mines and Energy, and other invited stakeholders participated in several discussions to determine the most critical cross-cutting considerations, and their respective roles in the development of the proposed regulatory roadmap (**Figure 2**).

KEY OUTCOMES/IMPACT

As critical background and framing context, NREL provided training on the four phases for technology market saturation (market preparation, market creation, market expansion, and market optimization) and how those phases translate to the new DER technologies (see **Figure 3**).

These include:

- **Market preparation** - addresses institutional barriers and market access that may be overcome by interconnection or net-metering policies.
- **Market creation** - addresses the lack of an existing market and public understanding with renewable portfolio standards and mandate policies.
- **Market expansion** - overcomes investment uncertainty and upfront costs with incentives such as tax rebates or grants.
- **Market optimization** - brings new considerations as market maturity progresses, such as energy equity and justice on the social side; whereas on the technical side, implications for the bulk power system as DER resources deployment increases (expected to be dominated by inverter-based resources).

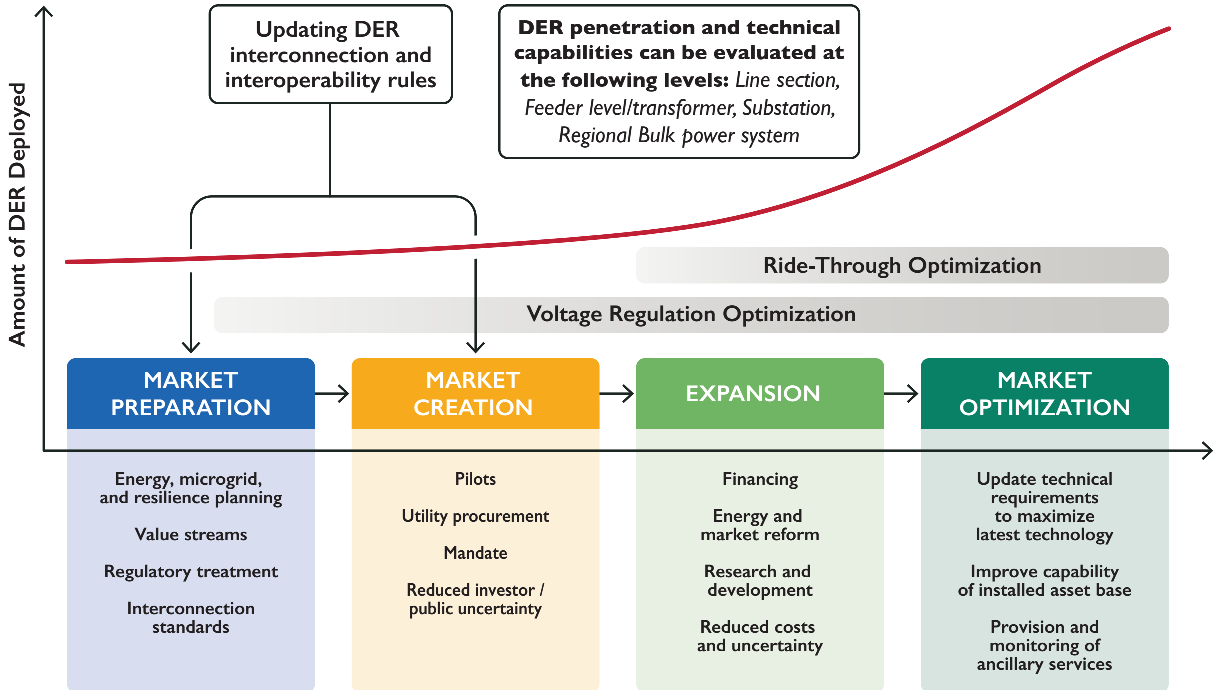

Figure 3. Overview of market phases for DER deployment

To address these four market phases and associated technical challenges, while best meeting interconnection process requirements and technical requirements in the regulatory roadmap, NREL suggested that CREG consider adopting a policy-stacking framework and the IEEE 1547 technical requirements and standards, which ensure that safety, power quality, protection, and general interconnection integrity requirements are met and up to code (see **Table 1**). NREL provided deep-dive training of the International Standard IEEE 1547-2018 as a benchmarking framework, specifically including:

- The design of IEEE 1547 as a technology-inclusive standard, applicable to all DER technologies interconnected on the distribution system
- Possible impacts of unintentional islanding, testing and verification, and interconnection processes on DER systems
- Important decision-making metrics for power system operators when considering new DER capabilities, and associated challenges and opportunities
- Enabling of new DER capabilities with the implementation of IEEE 1547-2018 to update DER interconnection, for utilization by power system operators.

In addition to the aforementioned frameworks, NREL also provided specific capacity building on different types of DERs and their unique technical and market considerations, as highlighted in **Table 2**.

Additional considerations can be found in NREL's final advisory documentation: https://www.nrel.gov/docs/fy23osti/84351.pdf.

Table 1. IEEE Standard 1547-2018 general requirements

GENERAL REQUIREMENTS SPECIFIED IN IEEE STD 1547-2018	
Safety	• Visible-break isolation device • Anti-islanding • Inadvertent energization of area electrical power system (EPS)
General	• Interconnect integrity: - Protection from electromagnetic interference - Surge withstand. • Integration with area EPS grounding • Synchronization limits for frequency, voltage, and phase angle (IEEE 67 criteria okay for some types of synchronous generators1).
Power Quality	• Limitation of DC current injection • Limitation of DER-caused voltage fluctuations: - Flicker (revised method) - Rapid voltage changes (new). • Limitation of current distortion • Limitation of overvoltage contribution: - Temporary overvoltage - Transient overvoltage. • Harmonics
Protection	• Response to short-circuit faults: - IEEE Std 1547-2018 requires the DER to cease to energize and trip • Open phase conditions • Coordination with area EPS circuit reclosing. • Response to abnormal grid conditions: - Appropriate to ensure grid stability (e.g., voltage and frequency ride-through capabilities) while maintaining safety of utility personnel
Note: Different requirements in IEEE Std 1547-2018 are set such that no specific technology is given preference, and the standard is technology neutral.	

Table 2. Examples of Unique DER Technical and Market Considerations

TECHNOLOGY	EXAMPLE TECHNICAL CONSIDERATIONS	EXAMPLE MARKET CONSIDERATIONS
Photovoltaics (PV)	• Distributed PV adoption should be evaluated at multiple scales (substation, circuit, region).	• Cost allocation and cost (un)certainty
Energy storage systems (ESS)	• Interoperability should be considered. • Integration with conventional electric grids requires specially designed topologies and/or control systems. • Costly design and debugging of each individual energy storage system.	• ESS integration has unique implications for the traditional utility business model. • Energy storage systems provide different functions to their owners and the grid, often leading to uncertainty as to the applicable regulations for a given project.
Hybrid energy systems (HES), including PV with storage	• To a large extent, wholesale electricity markets, electric utility regulation, and state energy policies were designed with the expectation that power generating facilities would consist of a single technology type. • Optimizing the design and operations of HES also requires development of controls, sensors, telemetry, metering, and other communications equipment to facilitate the coordinated operations of subcomponents with different objectives.	• HES create unique challenges for the design, operation, and regulation of wholesale electricity markets, for state regulation of electric utilities, and for the design and implementation of energy policies.
Microgrids (e.g. isolated PV with battery energy storage systems)	• Islanding operation should meet technical performance requirements for parallel operation (i.e., grid-tied). • Interoperability should be considered.	• Microgrid integration has unique implications for the traditional utility business model. • Microgrids provide different functions/services to their owners and the grid, potentially leading to uncertainty as to the applicable regulations for a given project.
Distributed wind	• Lowering technology costs, developing new markets, and improving turbine reliability • Improving integration and control • Improving prediction of long-term output	• Deployment cost reduction and reliability improvement necessitate policy considerations.
Electric Vehicles, vehicle to home (V2H), vehicle to grid (V2G)	Pre-approved equipment list	• Energy resale, tariff and fee considerations • Charging / discharging incentives and time of use
Dispatchable loads	• Traditional demand response assets couple with modern communications and control capabilities, • New types of dispatchable loads such managed charging of electric vehicles • Emerging research on ride-through for loads that have energy storage, all of which have unique technical considerations.	• Tariff and compensation structure
Small modular reactors	• Participation in international consortia	• Participation in international consortia
Fuel cells	• Especially for vehicle applications, inter-organizational technical considerations and planning are required (e.g., infrastructure requirements, codes and standards) • Stationary and V2G/V2H applications (i.e., ESS technical considerations apply)	• Largely, the hydrogen production/generation cycle is a form of energy storage (i.e., ESS market considerations apply) • Fuel cells have both stationary and vehicle applications (i.e., EV market considerations apply) • Fuel infrastructure policy, procedure, and market considerations. Production (i.e., reforming, electrolysis), transportation, and/or physical storage are examples.
Conventional (rotating machine) generators, including hydropower	• IEEE Std. 1547 is the governing standard, unless there is a conflict in requirements with the IEEE Stds for synchronous generators C50.12 and C50.13, in which case their requirements will prevail. • IEEE Std. 67 criteria for synchronization limits for frequency, voltage, and phase angle may apply for some types of synchronous generators.	Small-scale, distributed hydro pilots to gain experience with market operations (dependability, services, dispatch)

WHAT'S NEXT?

The CREG DER integration roadmap technical assistance highlighted the importance of understanding interconnection requirements with respect to the broader context of national energy policy goals, market trends, technical requirements, and stakeholder viewpoints, amongst other things. Going forward, it will also be necessary to define the specific DER technologies to be considered, as well as their intended use, technical requirements, and market adoption characteristics.

During the technical assistance discussions with CREG, NREL provided guidance to consider when developing new regulation(s) that address the technical requirements for DER interconnection processes. This ultimately has major implications for the traditional utility model and would require jurisdictional authority evaluation and stakeholder coordination. Due to the dynamic integration process of DERs, the coordination and strategies used to manage deployment will evolve as the market and overall energy-related goals begin to change. Thus, moving forward with the implementation of the DER integration and interconnection roadmap, NREL recommended completing more rigorous technical analysis for near-term DER integration, and optimizing the differing technical requirements at different DER deployment levels over time.

Together with USAID and the project's implementing partners USEA and Scaling Up Renewable Energy (SURE), NREL looks forward to continuing its support of the Government of Colombia, and specifically CREG, as they move forward with their regulatory roadmap for DER integration.

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INTEGRACIÓN EFICIENTE DE ENERGÍAS RENOVABLES VARIABLES AL SISTEMA COLOMBIANO

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www.nrel.gov/usaid-partnership/project-colombia.html

This work was authored, in part, by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the United States Agency for International Development (USAID) under Contract No. IAG-22-22434. The views expressed in this report do not necessarily represent the views of the DOE or the U.S. Government, or any agency thereof, including USAID.

NREL/TP-5D00-85345 • April 2023

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