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Enabling Efficient, Responsive, and Resilient Buildings: A Collaboration Between the United States and India

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***Abstract*—The United States and India have among the largest economies in the world, and they continue to work together to address current and future challenges in reliable electricity supply. The acceleration to efficient, grid-responsive, resilient buildings represents a key energy security objective for federal and state agencies in both countries. The weaknesses in the Indian grid system were manifest in 2012, in the country's worst blackout, which jeopardized the lives of half of India's 1.2 billion people. While both countries are investing significantly in power sector reform, India, by virtue of its colossal growth rate in commercial energy intensity and commercial floor space, is better placed than the United States to integrate and test state-of-art Smart Grid technologies in its future grid-responsive commercial buildings. This paper presents a roadmap of technical collaboration between the research organizations, and public-private stakeholders in both countries to accelerate the building-to-grid integration through pilot studies in India.**

***Index Terms*—responsive, buildings, integration, Smart Grid, international**

I. INTRODUCTION

The United States and India are among the largest and growing economies in the world, and they work together to address current and future challenges to provide a reliable electricity supply. While reliability of power supply is generally not a current concern for the United States, India has suffered from serious reliability challenges for ages. This was manifest in the July 2012 series of blackouts. A total of 36,000–48,000 megawatts (MW) of loads (~20% of the total installed capacity [1]) was affected by the blackout [2]. The blackout series exposed some of the major weaknesses of the Indian electricity grid structure and operation, and that resulted in a call for better communication and coordination across the grid. Some of recommendations by the expert committee included under-frequency and frequency-rate-change (df/dt)-based load-shedding relief in the utilities' networks, faster state estimation of the system at load dispatch centers for better visualization and planning of the corrective actions, frequency control through generation reserves/ ancillary services, and proper telemetry and communication at load dispatch centers. All of these issues point to the need for development of an integrated grid system with fast and responsive demand-side loads. The Government of India is taking measures to address the situation of aging grid infrastructure and integrated demand-side management. India's National Action Plan on Climate Change outlined a National Mission on Enhanced Energy Efficiency with actions for electricity sector reform. Following this, the U.S.-India Energy Dialogue was initiated in 2009 to provide a mechanism for joint activities to address energy issues and electric grid integration [3]. The U.S.-India Partnership to Advance Clean Energy (PACE) was launched in 2009 to accelerate the transition to high-performing, low-emission, energy-secure economies [4]. In November 2009, under PACE-R, which is the research component of PACE, the U.S. Department of Energy (DOE) and India's Ministry of Science and Technology established a Joint Clean Energy Research and Development Center (JCERDC). Under the JCERDC, the U.S.-India Joint Center for Building Energy Research and Development (CBERD) was established as an international consortium between the United States and India for research and development of energy-efficient building technologies.

Inputs to the work presented in this paper leveraged the research conducted by the authors for developing a roadmap of collaboration between India and United States under the aegis of the U.S. DOE's International Program [5] and CBERD collaboration with the Indian partners. One objective of CBERD is to develop a framework for the integration of building technologies and communications for the Smart Grid in India. The development of such a framework will benefit technical collaboration of various public-private stakeholders in both countries, for accelerating the development of grid-responsive buildings through pilot studies in India. The identification of technologies and their framework for integration with buildings for grid-responsiveness and cost optimization will be useful for U.S. deployments. The United States can also benefit from understanding the need and technical feasibility of grid-integrated technologies in building controls, and how such systems can provide both energy efficiency and demand-response values for cost-effective deployments. The final goal is to conduct joint tests and pilot demonstrations of in the later phases, followed by knowledge transfer to stakeholders in both countries.

The rest of this paper is divided into three sections: Research Methods, Results, and Discussion and Conclusion. In the Research Methods section we present the structure of the secondary information collection for answering our research questions. In the Results section we identify the priority areas for technology intervention, followed by a description of the potential roadmap for collaboration and technology research and deployment in India. In the Discussion and Conclusions section we describe the advantages of such collaboration for both countries, in terms of broadening the spectrum of innovation, market expansion for the Smart Grid, and strengthening bilateral ties.

II. RESEARCH METHODS

In this section we describe the methods adopted for secondary information acquisition to answer our research questions pertaining to building-to-grid (B2G) integration in India. These include: (1) What is an appropriate building sector for technology intervention in India? (2) Who are the potential collaborators in India and the U.S. for this research? (3) How can our work leverage other building-to-grid activities in India undertaken by the above collaborators? (4) Given the current state of Smart Grid development in India and technology availability, both nationally and internationally, what is an ideal roadmap for pilot demonstration of grid-responsiveness?

To identify the priority area of intervention, we first tried to understand the demand distribution in India, by building sector, and the projected growth of energy intensity in each sector. We then identified the key stakeholders in the electricity market, both in India and the U.S., including research institutions, governing bodies, private and state utilities, service providers, and technology vendors, for potential collaboration. Then we conducted thorough research on relevant policies and building-to-grid projects prior to preparing a relevant roadmap of technical collaboration. Our primary goal was to assist in technology deployment through expertise and experience sharing.

III. RESULTS

The scope of the B2G activities was delineated primarily based on the expertise of the lab in understanding responsive loads for Smart Grid deployments in the United States. This study leverages parallel Smart Grid activities by Indian and U.S. stakeholders. Its goal is to establish a sustainable B2G collaboration between the U.S. and India, which will facilitate integration of demand-side systems with supply-side systems to advance India's electricity reliability goals. The study will motivate Indian electricity markets by disseminating U.S. experiences and technologies for the uptake of demand-response (DR) pilot studies in India. The study delineates immediate and long-term intervention through systematic review of issues, U.S. experiences, and technologies that support local missions. In this section we discuss why we chose the commercial sector as a priority area of intervention and then describe the roadmap of collaboration for B2G integration in India. This is followed by a survey of potential bi-level technological intervention over a two-phase period.

A. Identify Priority Area of Intervention

The electricity deficit throughout India in 2013 is projected to be 10.6% [6], and the present estimated peak power shortage in the country is 11%–17% [7]. The chasm between supply and demand is constantly aggravated by rapid development, improvement in expected lifestyle, and explosive growth in commercial and residential floor spaces in India [8]. About 66% of the commercial stock projected to be in existence in India in 2030 is yet to be built [9]. Currently the commercial, residential, and industrial sectors account for 10%, 39%, and 24%, respectively, of the total 694,392 gigawatt-hours (GWh) of energy use [10]. While commercial sector electricity use is a smaller slice of the pie today, electricity demand in this sector is skyrocketing at an annual rate of 12%–14% [9]. Air-conditioning alone in commercial and domestic buildings make up ~40% of the electricity consumption in one utility's consumer base [11]. In comparison, the majority of the building stock in the United States has been built (See Figure 1). These building loads are not responsive to the electric grid needs and are, usually, inefficient, with high-energy consumption. The realized potential of these buildings for peak electricity reduction and improving electric grid reliability has been minimal, as the cost of enabling technologies is high. India, by virtue of its colossal growth rate in commercial energy intensity and commercial floor space, offers an opportunity for more affordable integration of the state-of-art grid responsive technologies at the prime of its development.

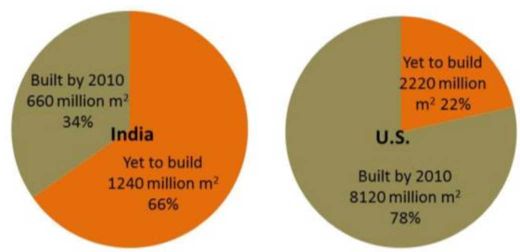

Figure 1. 2030 floor space forecast for the commercial building sector: India 1,900 million square meters (m^2) and U.S. 10,340 million m^2. India is expected to triple its floor space by 2030. Sources: ECO III and EIA [9].

B. Roadmap for Collaboration

The technology deployment roadmap for India, presented later, was developed based on technological gaps identified and parallel efforts of Indian and U.S. stakeholders. Figure 2 shows a map of stakeholders and collaborators for building-to-grid integration with specific priorities for each country. The arrows indicate two-way communication for information flow, knowledge transfer, test-bed sharing, and technology transfer. The public-private entities from India (displayed on the left side of Figure 2)—the Indian Smart Grid Forum (ISGF), Indian Smart Grid Task Force (ISGTF), Ministry of Power, state utilities, private utilities, technology vendors, Energy Service Companies (ESCos), and the building industry—will provide us with national roadmaps, conducive policies and standards, research facilities, and pilot sites and customer base for testing and validation of state-of-the-art grid-responsive building technologies.

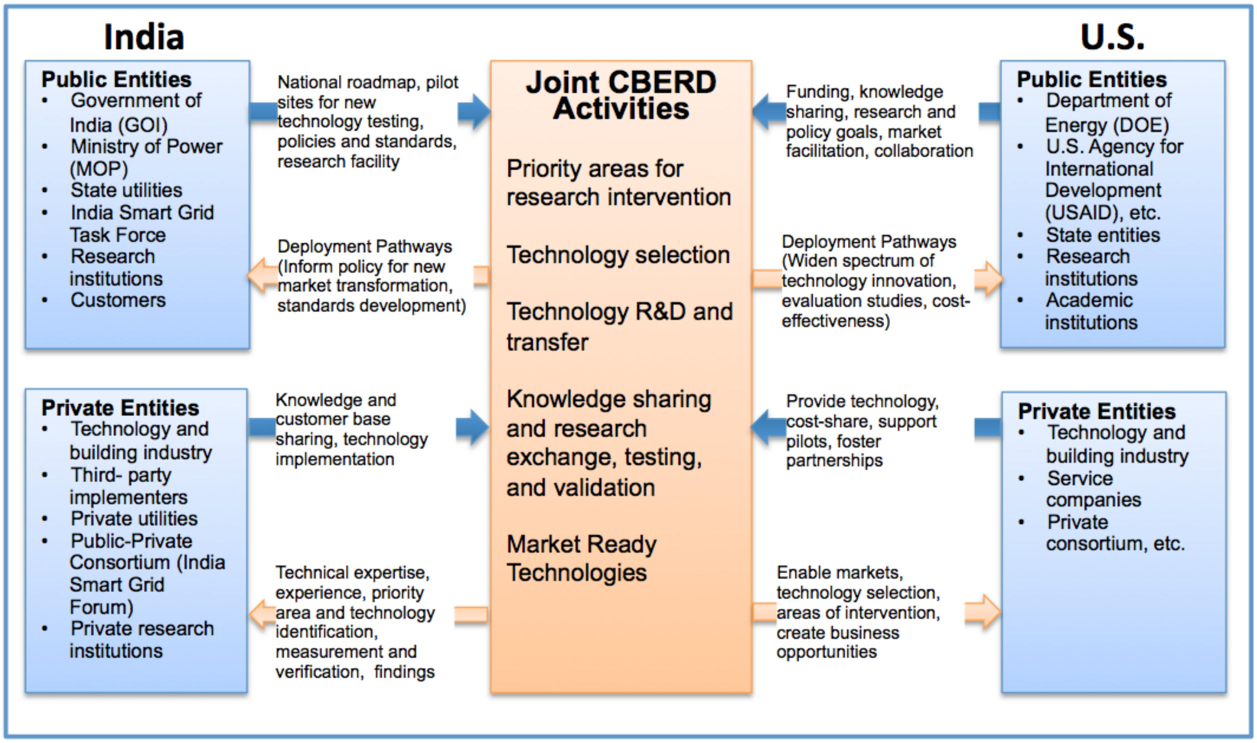

Figure 2. Interaction map of CBERD/B2G project in India

One example of a policy to promote the B2G work is India's National Mission for Enhanced Energy Efficiency that stipulates a target of 19 gigawatts (GW) avoided capacity addition and carbon dioxide (CO_2) emission mitigation of 98 million tons per year by 2014–2015 [12]. For the systemic growth of the Smart Grid in the country, the Ministry of Power (MOP) set up the India Smart Grid Forum (ISGF) [13] and India Smart Grid Task Force (ISGTF) [14].The Smart Grid roadmaps by the ISGF and ISGTF have proposed to conduct pilot studies. The peak-load management and advanced metering infrastructure will be implemented in ISGTF's proposed pilots.

Under the auspices of the seven working groups of the ISGTF, several activities encompassing market-based mechanisms for rapid Smart Grid adoption will be evaluated. These include demand-side financing, feed-in tariffs for individual renewable generators, and a differential tariff for reliable supply and transmission pricing models, including Locational Marginal Pricing (LMP) [15]. Another major power-sector reform initiative of the Government of India is the Restructured Accelerated Power Development and Reform Program (R-APDRP). R-APDRP is an extension of the Accelerated Power Development and Reform Program (APDRP) launched by the MOP in 2000–2001 as a last means for restoring the commercial viability of the Indian Distribution Sector, which was running at an alarming financial loss equivalent to 1.5% of the gross domestic product [16]. Several of the R-APDRP projects that specifically pertain to the building-to-grid integration are as follows [17]:

- Consumer indexing
- Metering of distribution transformers and feeders
- Automatic data logging for all distribution transformers and feeders and the Supervisory Control and Data Acquisition (SCADA) or Distribution Management System (DMS)
- Adoption of information technology applications for meter reading, billing, and collection
- Energy accounting and auditing
- Management Information System (MIS)
- Redressal of consumer grievances
- Establishment of consumer service centers
- Load balancing

The public-private stakeholders on the U.S. side (shown on the right side of Figure 2) like DOE, the U.S. Association for International Development (USAID), U.S. Trade and Development Authority (USTDA), and Smart Grid companies will provide state-of-the-art technologies for testing and validation and assist in pilot demonstrations through continued task skilled labor development and funding. Within the scope of this two-way collaborative framework, LBNL will share with Indian partners U.S. best practices and expertise in Smart Grid technologies and assist in development of demand-response (DR) strategies [18], deployment of open standard-based communication technologies like Open ADR [19] and measurement and verification M&V protocols. The U.S. partners will benefit from lesson learned from the pilot demonstrations and market expansion in emerging regions. A detailed roadmap of technology intervention for accelerating B2G integration in India is presented in the next subsection.

C. Technology Roadmap

Based on the background research on India's clean-energy goals, Table 1 outlines the integrated framework for India, describing the key requirements for B2G integration, technologies, and markets. Depending on the level of B2G integration (and, potentially, considering this as a phased approach) necessary, the requirements are classified as "basic" and "advanced." The advanced level supports and expands all the requirements of basic level.

TABLE I. REQUIREMENTS FOR BUILDING-TO-GRID INTEGRATION IN INDIA

Building-to-Grid Requirements		
Demand-Side Activities	**Basic**	**Advanced**
Energy Efficiency	• Energy Efficiency (EE) with higher investment for retrofits. • Promote new incentive programs.	• Energy-efficiency improvements with integrated control and automation. • Installation of advanced energy-efficient systems with considerable capital investment.
Demand Response	• Link DR with standard EE practices using semi-automated DR with advanced or day-ahead notification (e.g., time of day). • Apply well-studied DR strategies.	• AutoDR and advanced telemetry to communicate price or grid reliability information in "day-of" or ancillary services markets. • Aid ISGF goals for a 5% peak-load reduction target using DR by 2017 in the twelfth Five-Year Plan for India's Smart Grid [20]
Building System Behavior	• Encourage continuous energy management. • Semi-automated DR strategies.	• Fully automated dynamic building response to DR signals through BMS-based controls. • Pre-programmed responses (e.g., global temperature adjustment for HVAC).
Building Controls	• Building management systems (BMS) in commercial buildings programmed to manage HVAC and lighting loads for DR. • DR signals sent manually to building managers.	• Grid-integrated BMS with advanced control and automation technologies. • Potential of increased and reliable BMS response to DR and OpenADR integration. • Facilitate benchmarking and standardized report formats such as Green Button [21].
Grid-Integrated Intermittent Renewables Resources (IRR)	• Install renewable resources to supplement grid power. • Use on-site renewable generation and electric grid reliability.	• Buildings enabled to feed excess generation from renewable resources to the grid and benefit from credits (e.g., net metering). • Identified by ISGF as a key priority in India's Smart Grid Roadmap. With a target of 33% renewable generation by 2027 [20].
Distributed Energy Resources and Storage	• Use distributed generation and storage resources for DR and daily peak load management. • Provide pre-cooling or load shifting in buildings.	• Intelligent coordination to use/feed excess generation to electric grid during DR events. • Grid integration of advanced storage technologies (e.g., batteries, thermal energy).
Microgrids	• Integration of building-level Microgrids with basic metering technologies for accountability and local or grid reliability. • Use on-site generation, storage to island from grid power.	• Develop advanced and community-scale micro-grids with grid-integrated distributed energy resources. • Enable flexible DR and islanding capabilities in response to grid signals.
Electric Vehicles (EV)	• Electric vehicle (EV) charging stations at buildings and parking lots. • Enable charging integration with time-of-day rate schedules.	• Standards-based grid-interactive facility charging stations (charge or discharge). • Full electric grid integration of EVs for vehicle-to-grid (V2G) capabilities to meet 10% EV penetration goals by 2027 [20].
Transactions and Market Design	• Facilitate buildings to access price information from open markets using standardized platforms.	• Standards-based market/price transactions integrated with BMS and optimization. • Market design for transactive controls and to enable data analytics.

These phased activities are determined based on initial knowledge of the baseline methodologies and policies in India and can be subject to further refinement through B2G developments. The baselines provide key measurement and verification of customer load shed to DR programs. The phases align with those of ISGF roadmap, corresponding to the twelfth and thirteenth plan period (2013–2022). This integrated framework must expedite the integration of B2G technologies in new commercial buildings, to enable their participation in DR and avoid significant future retrofit costs. The "basic" level of B2G integration requirements refers to:

- Priorities in technology intervention based on compatibility with onsite energy-efficiency enabling systems and commercial product availability.
- Use of existing buildings and controls to support basic grid-integration capabilities, such as response to time-of-day (TOD) pricing schemes and reliability of DR programs.
- Leverage ongoing pilot initiatives and relevant policies.
- Align with the short-term goals and Smart Grid roadmaps by stakeholders such as ISGF, ISGTF, Nexant, Tata Power, and others.
- Aid pilot demonstration of semi-automated DR technologies and strategies for commercial buildings, as identified by the U.S. deployments [22].

The "advanced" level of B2G integration expands the "basic" level, and refers to:

- Priorities in technology intervention to maximize transition to the Smart Grid, renewables integration, distributed energy resources for a dynamic grid, and flexible load.
- Higher levels of automation, data collection, and real-time processing, with a focus on grid reliability, dynamic price responsiveness, and ancillary services.
- Upgrade or deployment of technologies to advanced systems, controls to provide sophisticated functionality (such as onsite generation), and renewable energy system integration.
- Stronger alignment with the long-term B2G integration goals delineated in the national Smart Grid roadmaps and/or missions.
- Assisting regulators with policies for codes and standards and mobilizing market transformation grid-responsive loads for existing and new buildings.
- Aiding demonstrations of advanced Auto-DR technologies and strategies for the future B2G integration through the U.S. experience [23], [24].
- Addressing cyber security issues in communications and interfaces pertaining to confidentiality of user information and integrity of DR systems.
- Assisting dispute resolution for unintended manual control action, and/or faulty actions for automated/semi-automated control schemes.

IV. DISCUSSION AND CONCLUSION

The building sector is responsible for 40% of total energy consumption and CO_2 emissions in the United States and is increasing faster than any other sector [25]. Commercial buildings in the United States waste approximately one-third of the energy they consume because of suboptimal operating standards. These buildings consume 18% of all energy produced in the United States. The lack of building systems integration alone costs the United States upward of $16 billion per year in lost efficiencies [26].

The Indian MOP launched the Bureau of Energy Efficiency (BEE) under the first Energy Conservation and Commercialization (ECO) project in India in 2002. This led to the development of voluntary energy-efficiency codes—the Energy Conservation Building Codes (ECBC) [6]. CBERD charted out a partnership plan for energy-efficiency projects in India. A preliminary energy-simulation-based analysis showed that enhanced energy efficiency in buildings could lead to annual energy savings of 60% in India [9]. The goal of the present study was to delineate a technology roadmap to leverage the existing energy-efficiency infrastructure in Indian commercial buildings and extend their capabilities for a smooth transition to grid responsiveness.

The Joint U.S.–India B2G collaboration initiative can act as a platform for LBNL and other relevant U.S. stakeholders to share expertise in Smart Grid technologies and apply the lessons learned from the U.S. deployments to the Indian context (e.g., DR and DER) in an integrated fashion to address both building-to-grid integration and energy efficiency. The key benefits to both the countries through this joint collaboration include:

- Enhanced ties between U.S. and Indian building energy researchers and industry;
- Integrated, proven, marketable building technologies for energy efficiency and grid responsive and resilient loads.
- Improved cost-effectiveness of technology development through enhanced joint collaborations that utilize the strength of both nations.
- Improved capabilities for both nations to leapfrog development of technologies and markets.

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