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PREPARING DISTRIBUTION UTILITIES FOR UTILITY-SCALE STORAGE AND ELECTRIC VEHICLES

A Novel Analytical Framework

GREENING THE GRID (GTG)
A Partnership Between USAID and Ministry of Power, Government of India

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ABSTRACT

Emerging distributed energy resources (DERs)—such as solar photovoltaics (PV), battery energy storage systems (BESS), and electric vehicles (EVs)—are expected to increase substantially in India in the coming years following policy-driven targets of the Government of India to modernize its electricity system, reduce greenhouse gas emissions (GHGs), and improve air quality. These emerging technologies can pose challenges to distribution utilities, forcing overhauls in planning and operational practices. They can also create challenges in power system infrastructure planning and cause more frequent system operational violations (e.g., network voltage bounds and loading thresholds) if not properly integrated.

The impacts on the localized power distribution grid from these emerging technologies manifest in increased infrastructure investments and erratic shifts in demand patterns. These impacts are not yet well understood, and analytic solutions are not readily available. To address these challenges, the National Renewable Energy Laboratory (NREL), in collaboration with BSES Rajdhani Power Ltd. (BRPL), developed an advanced power distribution system impact analysis framework of BRPL's distribution system. This framework helps analyze the readiness of the power distribution network to accommodate emerging technologies and the potential opportunities they might introduce. The framework has been predominantly set up to evaluate distributed PV, BESS, and EVs. In this collaboration between NREL and BRPL, we developed and evaluated the framework on two distribution feeders in the BRPL territory for various scenarios of BESS and EVs. BESS are evaluated for their effectiveness on the grid to mitigate present and future feeder overloading scenarios, and they are subsequently analyzed for their costs compared to the costs of traditional upgradation measures. Scenarios include assessing the effects of EV density on grid infrastructure upgrades and interlinking EV management with BESS integration.

List of Acronyms

BESS	battery energy storage systems
BNEF	Bloomberg New Energy Finance
BRPL	BSES Rajdhani Power Ltd
DER	distributed energy resources
DT	distribution transformer
EV	electric vehicles
GIS	geographic information system
GTG	Greening the Grid
HPC	high-performance computing
LCOE	levelized cost of energy
Li-ion	lithium-ion
NREL	National Renewable Energy Laboratory
PPA	power purchase agreement
PV	photovoltaics
RISE	Renewable Integration and Sustainable Energy
SAM	System Advisor Model
SAVFI	system average voltage fluctuation index
SAVMVI	system average voltage magnitude violation index
SAVUI	system average voltage unbalance index
SCADA	supervisory control and data acquisition
SCDOI	system control device operation index
SELI	system energy loss index
SOC	state of charge
SRPDI	system reactive power demand index

Executive Summary

Context and Problem Descriptions

Emerging distributed energy resources (DERs)—such as solar photovoltaics (PV), battery energy storage systems (BESS), and electric vehicles (EVs)—are expected to increase substantially in India in the coming years following policy-driven targets of the Government of India to modernize its electricity system, reduce greenhouse gas emissions (GHGs), and improve air quality. These emerging technologies can pose challenges to distribution utilities, forcing overhauls in planning and operational practices. They can also create challenges in power system infrastructure planning and cause more frequent system operational violations (e.g., network voltage bounds and loading thresholds) if not properly integrated.

The impacts on the localized power distribution grid from these emerging technologies manifest in increased infrastructure investments and erratic shifts in demand patterns. These impacts are not yet well understood, and analytic solutions are not readily available. To address these challenges, the National Renewable Energy Laboratory (NREL), in collaboration with BSES Rajdhani Power Ltd. (BRPL), developed an advanced power distribution system impact analysis framework of BRPL's distribution system. This framework helps analyze the readiness of the power distribution network to accommodate emerging technologies and the potential opportunities they might introduce. The framework has been predominantly set up to evaluate distributed PV, BESS, and EVs.

Methodology

In this collaboration between NREL and BRPL, we evaluated the framework on two distribution feeders in the BRPL territory for various scenarios of BESS and EVs. BESS are evaluated for their effectiveness on the grid to mitigate present and future feeder overloading scenarios, and they are subsequently analyzed for their costs compared to the costs of traditional upgradation measures. Scenarios include assessing the effects of EV density on grid infrastructure upgrades and interlinking EV management with BESS integration. Key outcomes of this research are as follows:

- Developed and validated an accurate, scalable end-to-end framework for evaluating the impacts of emerging technologies (BESS, PV, and EVs) on power distribution systems
- Developed models to characterize utility-scale BESS operations and economics across different use cases and developed methods to analyze isolated and stacked benefits of BESS with different control patterns
- Characterized various EV technologies deployed at different penetration levels for public, private, and commercial vehicles in terms of their aggregate demand profiles
- Identified and computed a suite of grid-readiness metrics for techno-economic assessments of network operation impacts under BESS control use cases and EV penetration scenarios
- Defined upgrade requirements for network infrastructure to mitigate possible violations of grid-readiness metrics and reduce potential customer service interruptions caused by an increase in overall system loading from EVs.

The work conducted for this project leverages many tools and capabilities unique to NREL. Data provided by BRPL—including feeder head and distribution transformer loading data along with all the technical specifications and schematics of two feeders in Delhi—underpin the model development and validation work.

After using specialized algorithms to improve the quality of the data, the distribution transformer profiles are used to perform multiyear, quasi-static time-series power flow analyses on detailed three-phase feeder models. NREL's high-performance computing (HPC) system is leveraged to allow for the parallel analysis of many potential future scenarios. Additionally, the developed architecture provides a reusable framework to analyze the impact of integrating increasing numbers of EVs and utility-scale batteries into distribution networks.

Results

Results discussed in this report show the effective application of the developed framework. Included in are critical building blocks for the analyses, such as aggregated EV demand profiles and preliminary voltage impacts. Energy storage integration for peak-shaving applications are also evaluated. These platforms are then integrated for simulation on NREL's HPC system for subsequent cost-benefit analyses. Using the simulation results and corresponding impact-metrics analyses, network upgrade recommendation models are developed and assessed for two Delhi feeders and the costs of an emerging technology upgradation approach is compared to a traditional upgradation approach.

These types of assessments will help BRPL and other utilities gauge the readiness of their feeders for integrating increasing numbers of EVs and energy storage as the distribution sector continues to transform.

The following four topics are investigated in this study, which have relevance for policymakers, utility planners and other decision makers beyond the case study analyzed:

- Reusable framework for distribution utilities
- Impact of BESS on distribution system losses
- Minimally sizing and controlling BESS for maximum benefits
- Essential and cost-effective pathways to deploy BESS (staged vs. all at once).

Scalability of reusable framework for distribution utilities: This effort developed a reusable framework for distribution utilities to assess the impact of emerging technologies (BESS, EV, and PV) on their power distribution grids. The framework contains three layers, as shown in Figure ES-1. The first and base layer is the distribution feeder topology assessment. The second layer is for distributed generation, such as rooftop PV or any generation resources commonly referred to as a DER. The third layer is dedicated to BESS. The fourth layer is built to include EVs. Overall, all four layers interact and provide a comprehensive assessment of challenges and opportunities from emerging technologies.

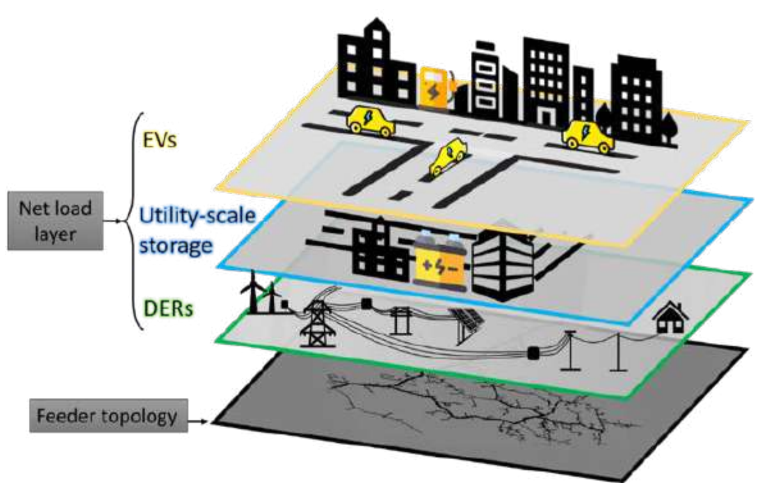

Figure ES-1. Modular layers in our reusable distribution analysis framework

This framework was simulated on NRELs HPC, and simulation runs exceeded 500 hours; however, the computational requirements for using this framework are not beyond a typical server or modern laptop. It is expected that BRPL engineers could run distribution feeder operation scenarios without the need for upgrades or simplification of models.

Analysis using this framework can be conducted outside of a supercomputing system or by purchasing software licenses given that we would like many utilities and other interested users to have access to this type of analysis. The solution framework is built entirely on open-source platforms and programming language.

Impact of BESS on distribution system losses: The main case study performed in this effort is on helping distribution utilities understand the possibility of deferring a distribution transformer upgrade by deploying a BESS in the neighborhood. Hence, the presiding question was understanding how a BESS affects system losses. Distribution transformers are generally designed to operate with maximum efficiency at or near 70% of rated power—in other words, transformer efficiency is affected by its loading. Appropriate battery charge/discharge settings on the test distribution feeders lead to reduced system losses. The reason being battery energy storage successfully displaces the transformer loading from less efficient part of the load curve to more efficient part of the load curve. Figure ES-2 depicts from our research results that for selected distribution transformers, combined system losses reduced when the BESS was performing peak shaving.

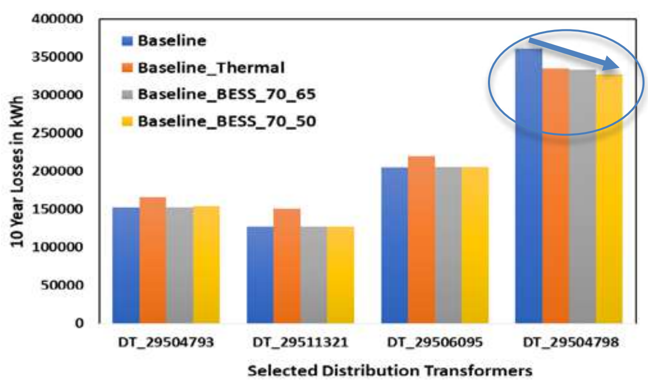

Figure ES-2. Impact of different battery control strategies on system losses

Minimally sizing and controlling BESS for maximum benefits: The peak-shaving mode of BESS requires the service operator to provide trigger values for peak shaving and base loading. The BESS will discharge power into the grid if the total power demand at the measured point—in this case, the distribution transformer—is greater than the peak-shaving upper reference limit. Conversely, the BESS will charge if the total power consumption at the measured point is less than the base-loading limit. It is important to ensure that charging the BESS occurs during the baseload loading periods (i.e., the valleys) to avoid overloading the distribution transformer during peak periods. After simulating various use cases, Figure ES-3 was generated to showcase the ability to achieve upgrade deferral with appropriate battery controls. Figure ES-3 depicts that for a certain distribution transformer, two different peak-shaving battery trigger points had varying impacts on overloading instances over 10 years of simulation.

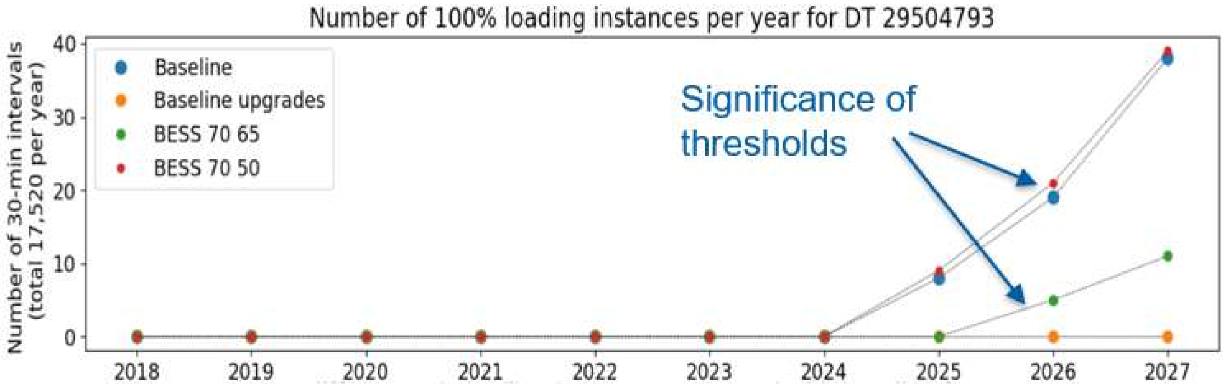

Figure ES-3. Count of 100% loading instances per year for selected transformer for different battery peak-shaving trigger points

Note: BESS 70 65 represents a control scheme where the battery operates to keep the loading of the distribution transformer between 70% and 65%. Simillarly for BESS 70 50, the battery operates to keep the distribution transformer between 70% and 50%.

Essential and cost-effective pathways to deploy BESS (staged vs. all at once): BESS are typically sized and deployed as full size; however, as a research exercise, we created three deployment scenarios (as shown in Figure ES-4): (1) standard deployment during the first year of the project (3,600 kWh), (2) staged deployment to meet the battery requirements, and (3) staged deployment by adding 200 kWh every year. The results of the staged deployment scenarios showed that capital costs can be 9.7% less for Scenario 2 and 13% less for Scenario 3 (Figure 87). Section 6.3.2 contains detailed descriptions on how we reached this result.

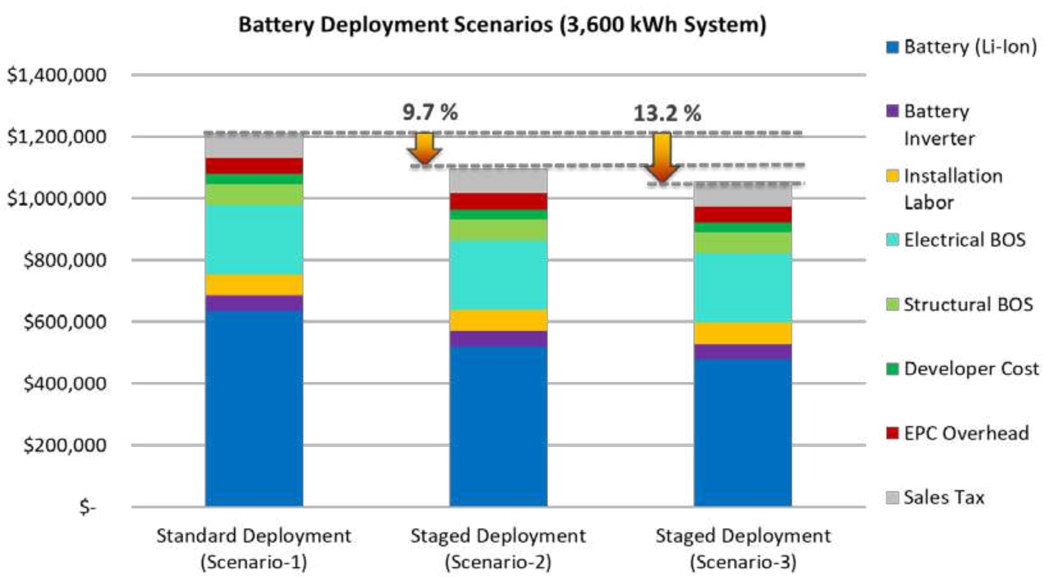

Figure ES-4. Capital cost comparison for different battery deployment scenarios

These topics are addressed throughout this report. Chapter 7 summarizes the notable outcomes.