CASE STUDY

ASIA LEDS PARTNERSHIP

Integration of Renewable Based Generation into Sri Lankan Grid

May, 2019

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Countries across the world are engaging in large-scale renewable energy (RE) deployment to meet ambitious low emission and sustainable development goals. The increased penetration levels of RE-based generation bring operational and technical challenges, particularly for network stability and security of power systems. However, such challenges can be overcome through a detailed understanding of the power system characteristics and required enhancements. The Ceylon Electricity Board (CEB)- a state-owned power utility of Sri Lanka responsible for the realization of the country's new renewable energy targets - embarked on the journey gradually, but later leapfrogged its learning through detailed analysis of grid integration process and challenges. The sequential and repetitive studies have paved the way towards realizing the country's ambitious goals and ensured a more reliable transition towards a greener future.

This case study discusses how the CEB approached the study on grid integration and the key learning therein. The lessons learnt by Sri Lanka are interesting and applicable worldwide.

Grid Integration Study has Resulted in Various Policy Thrust

The study has enabled the development of the country's RE sector of the country at an accelerated pace. This evidence- based study is now considered as the backbone of any decision-making process within the country's power sector. Based on the study outcomes, the recently-published National Energy Policy of the country suggested the development of RE sources as an important measure for enhancing energy security in the country. Sri Lanka has also committed to reducing 20% of its GHG emissions by 2030 by taking inputs from the study on its long-term RE development.

The study provided key technical recommendations for Sri Lanka to undertake such as establishing VRE forecasting system, grid scale storage units such as pumped hydro, RE monitoring and controlling desk for system control centre; implementing a network strengthening program; enhancing operational flexibility of plants, and other strategies such as enabling VRE curtailment right for the operator; and prioritizing RE for future development.

> Undertaking a grid integration study helped Identify the capability of the Sri Lankan power system to enable fourfold increase in renewable energy capacity additions with significant contribution towards reducing carbon emissions meeting Sri Lanka's Nationally Determined Contribution (NDCs) on GHG emission reduction.
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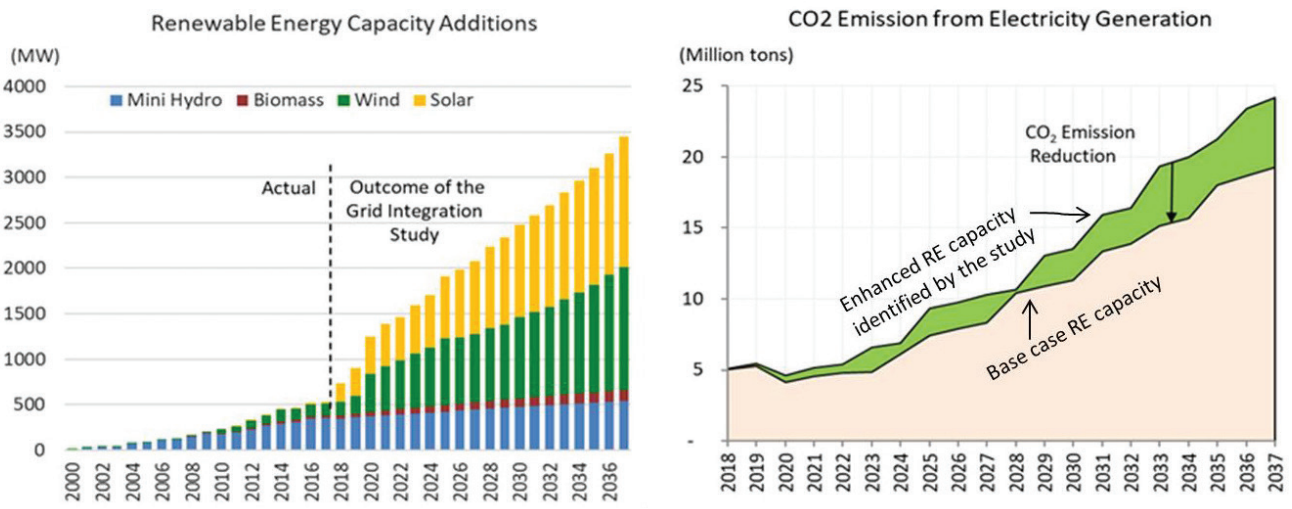


Source: Transmission & Generation planning Branch, Ceylon Electricity Board

Figure 1: Potential renewable capacity addition and GHG emission reduction identified from Sri Lanka's Grid Integration Study

Key Takeaways

- Grid integration studies can be a powerful planning tool for informing policy decisions on ambitions renewable energy and climate mitigation goals. The deployment of high variable renewable energy (VRE) generation is a long journey and raises many operational and infrastructural issues in the power system.
- Technical assessment of grid integration is an important part of the journey and therefore should be initiated along with the planning processThe use of effective modelling tools and scenario analysis enables a better understanding of the grid integration challenges. Assessment of renewable energy resources is an essential step to initiate a grid integration study.
- Grid-scale energy storage solutions such as pumped hydro storage effectively facilitates VRE integration by relieving the operational bottlenecks and improving the system's stability and reliability.
- In the case of Sri Lanka, the results from the study helped to identify priority measures for realizing large-scale RE integration and provided the technical basis for informed policy formulation.
- Grid integration studies are expensive and extensive. Thus, a clear definition of the study objectives and problem statement(s) can help effectively utilize the resources.
- An integrated approach to understanding the end-to-end challenges, i.e. from generation to distribution, is essential and requires the engagement of all authorities from the beginning.

- Thorough analysis of RE resource availability, site assessment, transmission capacity, and load scenarios can help reduce/ avoid RE curtailment.
- Parallel strengthening of the transmission network and enhancing mechanisms for improved grid stability are of equal importance to synchronize large uptakes from RE sources.
- Grid integration assessments are a continuous/repetitive process.
- Use of effective modelling tools and scenario analysis enables a better understanding of integration challenges.

Context

Sri Lanka is a lower middle-income country and its electricity demand is growing at a rate of 5%[i] with rising economic activity. Along with other countries, Sri Lanka has vouched for its national obligation towards mitigating climate change impacts to the United Nations Framework Convention on Climate Change (UNFCCC). Accordingly, country's ambitious target is to enhance its renewable energy mix from the existing 50% to 60% from 2020 onward and to reduce GHG emissions by 20% over the Nationally Determined Contributions (NDC) target[ii]. To achieve this, the country has planned to develop total of 894 MW of wind, 1009 MW of solar, 99 MW of biomass, and 474 MW of mini-hydro. The island's power system currently has an installed capacity of 4048 MWi.

Variable renewable generation is seasonal, intermittent and geographically dispersed across the island. Country's power system is starting to experience the emerging challenges of variable renewables. Thus for the CEB, which operates Sri Lanka's power system, the challenge is to achieve the set transformation while ensuring network security and reliable supply of electricity. Before 1990, almost the entire electricity generation of Sri Lanka was from hydro resources and the country had a predominantly hydro-based generation system until about 2000. Almost all the major hydro resources have been already harnessed and energy contribution from other renewable energy resources such as wind and solar has been gaining momentum. With the increase in variable renewable energy share the power system stability concerns and operational bottlenecks were emerging and as a result a comprehensive renewable energy grid integration study was initiated by the Ceylon Electricity Board.

Therefore, a detailed "RE Grid Integration" study was conducted to provide answers and further insights to the perceived challenges. Deployment of additional RE capacity into the grid through new projects was moderated until the study was completed and solutions were identified. A team comprising of experts from operation, transmission, and planning departments were assembled to address various concerns about performance of RE resources; system operation analysis; transmission stability analysis; short, medium, and long-term optimization; technology cost; as well as the techno-feasibility study of the entire integration plan. Each of these have been further discussed in detail in the next section.

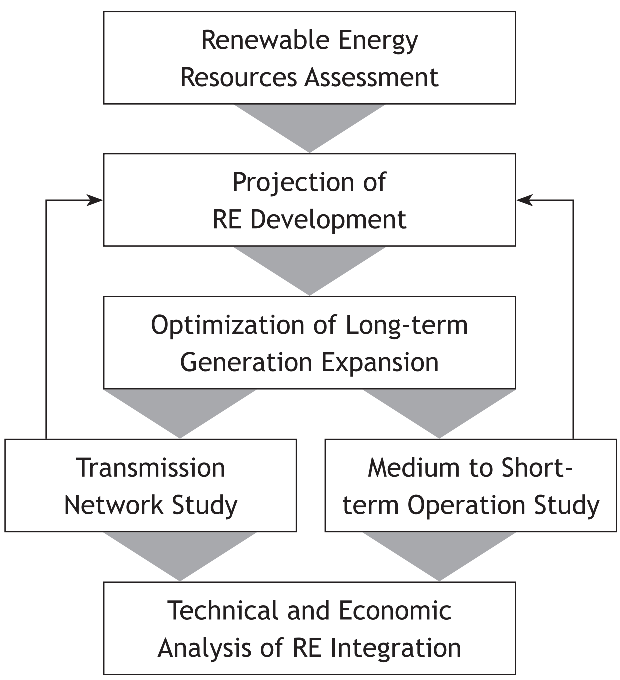
As part of the study, a final detailed implementation plan was developed, which was subsequently incorporated into the long-term generation and expansion plan of the CEB. As part of the planning process, the CEB carries out generation and grid expansion forecast every two years, spanning a 20-year time period. The long-term plan is then implemented to adhere to the government's policy directives. Therefore, incorporating the consolidated findings and implementation plan of the grid integration study into the CEB's long-term plan ensures that the RE integration takes place in an informed and time-bound manner in the country.

The study has helped put in place a long-term implementation plan to support the country in achieving its NDC goals going forward. In the absence of the study, there would have been delays. The study has not only helped CEB officials gain an in-depth understanding of what large-scale RE grid integration means, but also how the same can be practically realized in a successive way, through short, medium and long-term goals. The RE development program envisaged in the study is now gaining momentum with strong implementation support under different national-scale initiatives, thereby leading to the realisation of the NDC targets.

The Grid Integration Study

Grid integration is the practice of developing efficient ways to deliver VRE to the grid. Grid integration addresses issues such as complementarity of RE resources and conventional generation; maintaining optimum transmission grid operation and condition when adding large amounts of intermittently available and disperse RE sources such as solar and wind; and meeting end-use demand during periods of low RE generation. Robust integration methods maximize the cost-effectiveness of incorporating VRE into the power system while maintaining or increasing the system stability and reliability[iv].

Grid integration studies are carried out to investigate the technical challenges; provide answers and insights into specific challenges of RE integration, which are usually not addressed by conventional generation and transmission-capacity expansion, and planning exercises alone. A grid integration study helps to evaluate a power system with high levels of VRE resources. A grid integration study simulates the operation of the power system under different future VRE penetration scenarios, identifies reliability constraints, and determines the relative cost of actions to integrate VRE.



Source: Study Report on Integration of Renewable Based Generation into Sri Lankan Grid, Ceylon Electricity Board

Figure 2: Grid Integration Study: Overall Methodology

The CEB initiated the grid integration study to determine how much of VRE the country can reliably and economically integrate into its power system to achieve its ambitious RE targets and to utilize the available indigenous RE resources. The study's objectives, scope, and the methodology were determined in line with this overarching objective. The overall study process has an integrated approach with key power system planning functions namely capacity expansion study; system operation study; system stability; power flow study covering short-term, medium-term and long-term integration concerns[iii].

RE Resource Assessment: As the first step, the performance of RE resources was evaluated to understand their characteristics such as variability, seasonality, and energy production. RE sources such as mini and large hydro; wind; solar; and biomass were evaluated during this step. Actual site measurement data, such as wind velocity and solar irradiance were gathered from the archives of multiple years. With the use of performance prediction tool, titled "System Advisory Model" (SAM) developed by National Renewable Energy Laboratory (NREL), wind and solar PV resources were modelled. Five wind regimes and two solar regimes were modelled with real measurement data to represent the island's dominant wind and solar resource locations. Modelling done for large hydro resources used historical inflow data and the hydro-thermal optimization tool available in-house with the CEB. The study resulted in a detailed understanding of the total RE generation possible, disintegrated by source and site.

Projection of RE Development: In the next step, different future scenarios of RE development were projected based on policy pathways, technical aspects, and other driving factors. Analysis of different scenarios allowed identification of potential challenges of scaling up of VRE technologies, such as transmission network availability/capacity, power system stability, and demand loads.

Optimization of Long-term Generation Expansion: Subsequently, a capacity expansion planning study was conducted for different RE penetration levels, which resulted in different optimized expansion scenarios, including conventional generation technologies.

Transmission Network and Operation Studies: The transmission network study investigated the steady state and dynamic behaviour of the power system at different VRE penetration levels. This provided an understanding of the VRE penetration level at which the power system stability is adversely affected. The system operation study investigated the operational challenges and constraints that would emerge due to high penetration levels of VRE generation. Both these studies were conducted in parallel with coordination to provide vital decision-making information on VRE integration.

All the studies together led to better optimization of long-term generation and effective transmission expansion planning.

Results of the Study

Thorough analysis of RE resource availability, site assessment, transmission capacity and load scenarios can help reduce/ avoid RE curtailment:

In the case of Sri Lanka, the medium and short-term operational study revealed scenarios of low load periods versus high RE generation as shown in Figure 3v. An analysis of the economic load dispatch indicates high generation surges when all sources are feeding more than the demand load subjected to operational constraints. Thus, during such period, grid operators are forced to induce RE curtailments[1].

In the operational study, solutions to avoid curtailment were explored. The study helped identify that the pumped hydro storage technology was a viable solution to utilize the additional power generated by RE sources during low-load periods, thus alleviating operational bottlenecks.

Figure 4[v] illustrates the economic dispatch simulation for a typical windy day in 2025 with

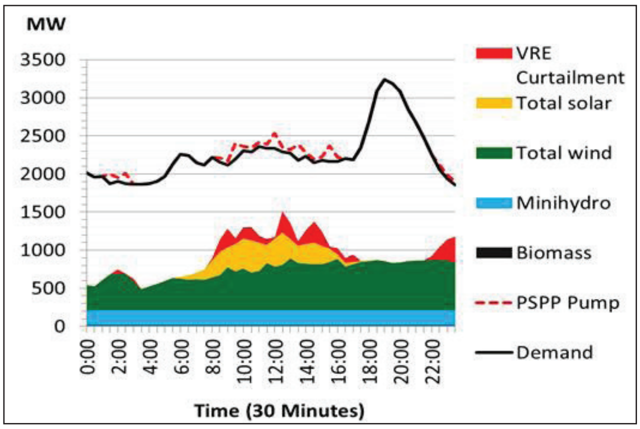


Figure 3: Variable Renewable Energy (VRE) Curtailment

high wind production. With the introduction of the pumped hydro plant (200MW), moderate VRE curtailments were observed during the same period. It is estimated that through pumped hydro storage, 50-200 MW RE curtailment can be avoided at different points of time in a year. Similarly, different study scenarios based on VRE penetration level, seasonality, plant operational parameter etc. were analyzed to investigate integration concerns.

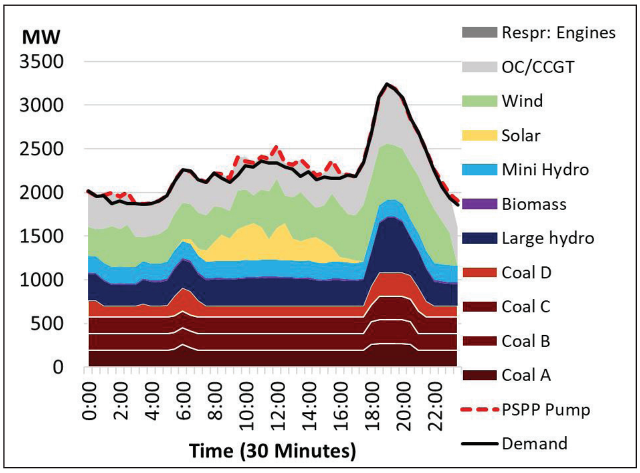


Figure 4: Economic Dispatch simulation

Parallel strengthening of the transmission network and enhancing grid reliability is of equal importance to synchronize large uptakes from RE sources:

In the power system stability study, frequency and voltage stability were investigated for different penetration levels of RE sources. A short-term frequency stability analysis was performed to evaluate the impact of large uptake of solar energy. Figure 5, illustrates that higher the solar penetration levels, larger is the frequency

1. Curtailment is the reduction in the output of a generator from what could be otherwise produced given available resources, typically on an involuntary basis. Curtailment can happen for a variety of other reasons, such as transmission congestion or lack of transmission access, low voltage, or interconnection issues. Since in most generation-based agreements, curtailment can affect the revenue, the owners of wind and solar generation are often concerned with impact of curtailment on project economics. Thus, it is an important issue, and systems should be in place to balance and accommodate additional generation.

variation, giving rise to instability and supply concerns. It was found that the implementation of frequency response reserves from additional power plants and timely implementation of network strengthening projects are important to proceed with the planned RE development.

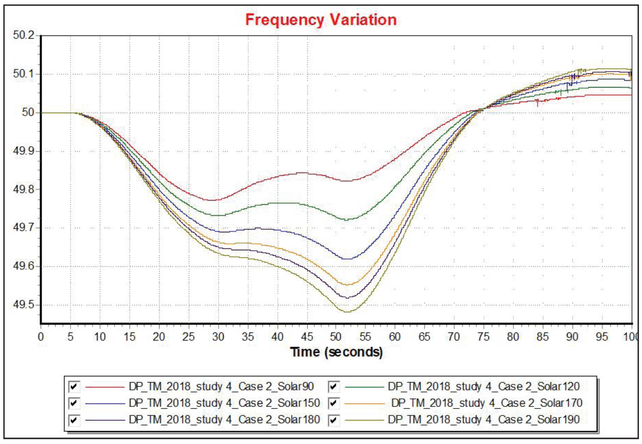


Figure 5: Frequency Response

Key Findings

Grid integration studies are expensive and extensive. Thus, a clear definition of the study objectives and problem statement(s) helps to effectively and efficiently execute the study activities. To perform a comprehensive grid integration study considerable effort to collect the necessary data and to develop the system models with appropriate software tools are a prerequisite. Gathering the best available data of RE resources, technical and operation parameters of the plants, transmission network and system operational model requires much attention at the initial stage of the study.

It is important to have an integrated approach to understand the end-to-end challenges, i.e. from generation to distribution. All stakeholders responsible for the generation, transmission and distribution should collaborate and participate in the grid integration study. With the CEB being the only operator in Sri Lanka's power sector, the entire study was conducted by CEB - drawing on its knowledge and experience as well as engaging in hands-on learning through the participation of in-house resources. Being the other main stakeholder, Sri Lanka Sustainable Energy Authority who hold the resource sights of the country provided the essential resource data to perform the study.

Grid integration assessments are a continuous/ repetitive process. Two rounds of integration study have been completed, with progressive improvement from the previous study. The first study was conducted in 2016 using a conventional operation simulation tool, generating multiple scenarios to identify the integration possibilities of the power system, mainly to support the decision-making process. Subsequently, two rounds of updates to the study were performed by incorporating additional data and information leading to new scenarios analysis, changes in long-term demand projection, as well as using advanced modelling software such as the Stochastic Dual Dynamic Programming (SDDP) and NCP (Short-term dispatch simulation) tools developed by PSR Energy Consulting and Analytics.

References

i. Long Term Generation Expansion Plan 2018-2037, Ceylon Electricity Board, Sri Lanka, June 2018, Available at https://www.ceb.lk/publication-media/planing-documents/46/en

ii. NDC, Sri Lanka, September 2016, Ministry of Mahaweli Development and Environment, Sri Lanka https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Sri%20Lanka%20First/NDCs%20of%20Sri%20Lanka.pdf

iii. Ceylon Electricity Board (December 2016), Integration of Renewable Based Generation into Sri Lankan Grid

iv. Integrating Variable Renewable Energy into the Grid: Key Issues. National Renewable Energy Laboratory. Greening the Grid, 2015. Available at http://greeningthegrid.org/resources/factsheets/integrating-variable-renewable-energy-into-the-grid-key-issues

v. Photo Credit: Integration of Renewable Based Generation into Sri Lankan Grid, Transmission & Generation Planning branch, Ceylon Electricity Board

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