Grid integration costs; a discussion of competing concepts, emerging approaches, and overall relevance

Thomas Nikolakakis
Power Sector Transformation Team

ETSAP workshop, Paris, 6th June 2019
Events

Regional Workshop in Brasilia (February 2019), International Forum in Berlin (April 2019), CEM Ministerial Meeting in Vancouver (May 2019), 10 workshops

Over 400 expert attendees in total

Webinar series*

Bi-weekly webinar series since November 2018

500+ Registrants

* https://www.irena.org/renewables/Knowledge-Gateway/webinars
About integration costs

» In general, integration costs refer to **additional costs** incurred in the power system by integrating a specific type of a **generation technology**

» Estimation of **VRE related integration costs** is key topic for the energy transition as VRE are gradually becoming the backbone of energy systems

» A more focused, generally accepted **definition** of integration costs doesn’t exist. There is a lot of controversy related to:
  » Which **cost elements** comprise integration costs
  » The **methodology** used to estimate them

» Regardless of the approach followed assessment of integration costs is **complex process** - usually part of a greater VRE integration study- and subject to a number of **assumptions and simplifications** that greatly affect results

» The power sector is changing fast. Any methodology to assess integration costs needs to be able to reflect on the **current reality** (i.e. account for costs of new technologies, batteries, EVs, demand response, heat pumps, electrolyzers etc)
VRE integration costs is a key topic for the energy transition

Variable renewables like solar and wind power will supply up to 64% of total electricity generation.

IRENA is tasked to support member countries assess:
  - a) relevant costs of competing technologies
  - b) the cost of the energy transition

Source: *Global Energy Transformation: A Roadmap to 2050*, IRENA, 2019
The focus around costs is shifting into flexibility investments

Utilities are lacking experience with operating power systems with VRE

- VRE integration imposed by policies (e.g. RPS in USA, 20/20/20 in EU)
- Assessment of integration costs mainly performed to assess "hidden costs" in monopolistic environments and/or re-assess tariffs
- Focus: OPEX costs (balancing costs)

VRE peaking up

- VRE becomes cost competitive, relevance is shifted towards identifying optimal mix of RE
- Improved computational tools allow to study much larger areas
- Flexibility identified as key cost mitigation measure

VRE becoming the backbone of power systems

- At very high shares of VRE Electrification becomes relevant
- CAPEX costs will be dominant over OPEX (T&D, DSM, storage, P2H, V2G, Hydrogen from VRE)
Components of integration costs found in literature

INHERENT CHARACTERISTICS OF SOLAR AND WIND RESOURCES

1. Variability
2. Uncertainty
3. Location specific

Efforts to disaggregate costs can be relevant for setting research and policy priorities based on magnitude of each cost element.

Allocation of integration costs on top of technology LCOE has been used as a metric to compare technologies.

Nevertheless, isolation and accurate disaggregation of costs is very complex and subject to caveats and uncertainties.
### Factors and controversies affecting estimates of integration costs

<table>
<thead>
<tr>
<th>Area of discussion</th>
<th>Difference of perspective / Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point of view</strong></td>
<td>Private entities</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Social Planners</td>
</tr>
<tr>
<td></td>
<td>Interaction cost among technologies</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Integration costs of new technologies</td>
</tr>
<tr>
<td></td>
<td>Lost revenues</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Cost to consumer and society</td>
</tr>
<tr>
<td></td>
<td>VRE responsible for reduced utilization rates of inflexible technologies</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Financial survival based on market forces</td>
</tr>
<tr>
<td><strong>System assumptions</strong></td>
<td>Inflexible system</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Flexible system</td>
</tr>
<tr>
<td></td>
<td>VRE on top of existing system</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> VRE + new flexibility assets</td>
</tr>
<tr>
<td></td>
<td>No sector coupling (same demand levels)</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Sector coupling (demand changes)</td>
</tr>
<tr>
<td><strong>Methodology used</strong></td>
<td>Costs comparison</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Cost benefit analysis</td>
</tr>
<tr>
<td></td>
<td>Non optimized approach</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> Optimized approach</td>
</tr>
<tr>
<td><strong>Change of relevance at different stages of the energy transition</strong></td>
<td>Low VRE shares (Focus on operational impacts)</td>
</tr>
<tr>
<td></td>
<td><em>VS</em> High VRE shares (Focus on flexibility investments)</td>
</tr>
</tbody>
</table>

Adapted from AGORA, 2015
Approaches for estimating integration costs:
System integration cost

» Compares relevant costs of different technologies considering system effects

» Inherent caveats:
  » Using a single benchmark technology to replace VRE is inaccurate
  » Isolating the non-linear nature of these costs is very challenging if not impossible

» Doesn’t account for system benefits; can’t be used to decide if one technology is beneficial for the system

Source: Holtinen et al, WIW, 2018
Approaches for estimating integration costs: System value - cost benefit analysis

» Used to compare direct costs of VRE versus net system value
» System value can only be estimated through the comparison of a low and high VRE scenario
» Net system value strongly depends on system flexibility and VRE penetration levels (i.e. underlying assumptions)
» Integrating VRE makes sense for as long as direct VRE costs are lower than system value

Source: Holttinen et al., WIW, 2018
IRENA approaches the issue of integration costs from the viewpoint of the social planner.

The idea is to assess if the reaching very high shares of VRE (>60%) comes at a net cost or benefit for the whole system.

Focusing on system effects (impacts on the non-VRE part of the system) will be irrelevant at very high shares of VRE.
Approaches for estimating integration costs:
Total system cost

- Early stages
- Midway
- Well advanced

Carrying capacity of the grid before flexibility measures
Carrying capacity of the grid after flexibility measures

- Deployment of flexibility measures like energy storage, demand side management (DSM) and sector coupling shift the carrying capacity of the grid to the right
Approaches for estimating integration costs: Total system costs

- Conceptually straightforward approach, free of caveats
- The reference and high VRE scenarios might be composed of completely different mix of assets
- Use of optimization tools and consideration of investments in flexibility can give valuable insights
- Consideration of how sector coupling changes future demand and system flexibility adds complexity in the analysis, but opens us potential for high-VRE net-benefit outcomes
- Its aim is not allocation of additional costs to different stakeholders
Examples of studies focusing on total system costs

The total system cost approach using advanced optimization tools is emerging.

Results strongly depend on CAPEX assumptions – more recent studies have lower CAPEX (and target year).

A larger number of studies looking into high VRE scenarios and sector coupling need to be performed to get more valuable insights.
Points to be addressed

» Defining a metric for “integration costs”; Which elements should be included (i.e. flexibility investment, grid investment, cost due to system element interactions etc)

» Agreeing on an appropriate methodology to quantify integration costs; which tools are best suited to assess them

» How to best communicate results of integration costs studies
Power Sector Transformation team work on modelling
Goal: To guide the development of effective electricity storage policies for the integration of variable renewable power generation

Part 1: Overview for policy makers

Part 2: Methodology of the framework

Part 3: Electricity Storage Use Cases

Hornsdale Power Reserve in South Australia (100 MW/129 MWh)

Source: Tesla 2017
IRENA’s structure on modelling energy systems with VRE

Market design, regulation, business models
- Forthcoming Report: *Adapting electricity market design to high shares of VRE* (Q2 2017)
- Country regulatory advice
- Power sector innovation landscape report (Q4 2017)

Long term, least cost capacity expansion plan
- Best practices in long-term scenario-based modelling* report, *Planning for the renewable future*
  - Recommendations are to be discussed at a Latin American regional workshop (2017 Q3)

Unit commitment and economic dispatch
- Production cost modeling
- Developing *flexibility assessment* to be applied to 5 REmap countries
- Developing a global *storage valuation framework*, to assess the value of storage in different markets

Grid studies
- Technical network studies
- A guide for *VRE integration studies* is upcoming (2017 Q2)
- Technical assessments for larger systems

Find the optimal pathway for power sector transformation
Storage Valuation Framework - Methodology

- The SVF discusses a methodology to assess the value of storage: a) for the whole system and b) from the view point of an investor

- The methodology focuses on modeling aspects

- cost refers to the cost of building and operating a storage project under a specified use case

- benefit refers to the combination of project-level and system-level benefits attributable to the project

- monetizable benefits are less than the costs, making the project economically infeasible

- Results of methodology can support policy makers on what regulatory mechanisms could be in place to make storage project feasible.
PLEXOS is used to simulate future VRE scenarios in Dominican Republic

Analysis using PLEXOS has the following objectives:
- Assess future flexibility; work with grids team to fill gaps identified
- Assess cost, operational and environmental benefits of VRE

1-week dispatch for the 2030 REmap scenario

Production costs ($million)
The PST team assessed potential benefits from improved operational practices.

- The analysis incorporated a) synthetic day-ahead VRE forecasts to account for the impacts of VRE uncertainty in future VRE scenarios, b) synthetic intra-day VRE forecasts that can be used multiple times within a day to inform intra-day re-dispatch.

**Graph:**
- **Secondary reserve requirement with 95% reliability**
- **System Benefits from Improved Operations**
  - 12 Million USD/year in savings
  - Improvement in Production Costs ($ million) and VRE curtailment (%)

**Table:**
- REmap
- Improved Operations
- Production Costs ($ million)
- VRE curtailment (%)
Launch at 16th Meeting of IRENA Council

- Forthcoming publication:
  - Thailand flexibility assessment
- Capacity Building
  - Cuba – Requested in 9th Assembly
  - Thailand – As part of ASEAN (together with REmap)
  - Central America – As part of CECCA (together with REmap)
Power system modelling and the IRENA FlexTool

FlexTool in the planning process

<table>
<thead>
<tr>
<th>Optimal Capacity Expansion</th>
<th>FlexTool Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Operation</td>
<td></td>
</tr>
<tr>
<td>Grid Studies</td>
<td>Dispatch Models</td>
</tr>
<tr>
<td>(Power Factory(^1), PSS/E2)</td>
<td>(PLEXOS-ST(^3), SDDP(^4))</td>
</tr>
<tr>
<td>1 Second</td>
<td>1 Hour</td>
</tr>
<tr>
<td></td>
<td>1 Year</td>
</tr>
<tr>
<td></td>
<td>10 Years</td>
</tr>
<tr>
<td></td>
<td>50 Years</td>
</tr>
</tbody>
</table>

Capacity Expansion Models (PLEXOS-LT\(^3\), Opt-Gen\(^4\))
Energy Planning Models (Message\(^5\), MARKAL/TIMES\(^6\))

\(^1\) Copyrighted by DIgSILENT GmbH
\(^2\) Copyrighted by Siemens PTI
\(^3\) Copyrighted by Drayton Analytics Pty Ltd, Australia and Energy Exemplar Pty Ltd, Australia
\(^4\) Developed by PSR
\(^5\) Developed by the International Atomic Energy Agency (IAEA)
\(^6\) Developed by the International Energy Agency (IEA)
No flexibility issues identified in 2030 even if the year considered has low hydro inflows (dry year scenario)

Reference year is 100% RE while dry year 86%

Excess VRE generation of 25% in reference and 8% in dry year

Options to reduce curtailment:
  - Active cross border market with Argentina or Brazil is in place to export
  - Explore sector coupling such as power to gas, power to heat or electric vehicles

MIEM sees the FlexTool as a useful complement to their current planning tools, as a tool that provides further insight on flexibility of the power system

<table>
<thead>
<tr>
<th></th>
<th>2030 Reference</th>
<th>2030 Dry Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtailment^</td>
<td>1920</td>
<td>609</td>
</tr>
<tr>
<td>Loss of load</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spillage</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reserves inadequacy</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
IRENA Knowledge Framework

- Identify a set of quantitative indicators to:
  - Filtering measures and signal a potential challenge
  - More than 20 indicators and measures over the period 2000-2018
    - China, Germany, Ireland, Italy, Portugal, UK, USA (ERCOT)

- Link countries experiencing integration challenges with other countries that solved such issues and share similar enabling conditions

- Synergies with other IRENA products:
  - REmap: enhance a plan for a target year by suggesting measures
  - FlexTool: measure could point out to an in-depth flexibility assessment with the tool
  - IRENA workshops: support other teams by highlighting countries with experience on a specific topic

Source: Hirth and Ziegenhagen (2015)
Thomas Nikolakakis
Associate Analyst
Energy Systems Modelling

TNikolakakis@irena.org
Planning early is key to minimize integration costs

**Impacts of VRE not yet being felt**
- Plan early for high shares of VRE. Develop pathways
- Establish grid codes
- Start strengthening the grid

**VRE affects system operations**
- Unlock existing flexibility
  - Improve operations
  - Market restructuring
  - Increase pooling area
- Investments on flexible generation
- Launch DSM
- Roll-out V2G

**VRE affects system reliability. Electrification becomes relevant**
- Investments on storage
- Electrify industry and buildings (heat-pumps and electric boilers)
- Dispatchable clean power
- Seasonal storage hydrogen production

Stages of power sector transformation