

# International Experience of Grid Challenges Associated with High Penetrations of Renewable Generation

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**Abstract**— India has ambitious plans to increase the installed capacity of Renewable Energy (RE) to 175GW by 2020. Accommodating such a volume of generation capacity will have a profound impact on the power system. While the target installed capacity is the subject of many headlines, it is the existing grid itself where many of the challenges will be faced. These challenges include transmission congestion, voltage support, reactive power balancing and infeed management. Unless addressed, such factors will present a barrier to achieving the ambitious RE capacity targets. This paper will explore the approaches taken in North America, the UK and in Germany, showcasing some of the latest projects and relating their relevance to India.

**Keywords**:- *renewable integration, grid interconnection, renewable energy, congestion management, grid innovation*

## I. INTRODUCTION

India has set ambitious targets for RE and this has significant grid integration challenges, particularly surrounding grid augmentation and congestion management. As other nations worldwide have been implementing RE growth plans and network innovation programs, this paper looks to draw on and consolidate the experience gained.

In North America, the focus has been on Distributed Energy Resources (DER) and the role of renewables and energy storage in integrated grid planning as alternatives to traditional grid infrastructure or peaker plants to address load growth and peaks. The structure of incentives, in the form of net metering, has reduced utility income and reduced stock valuations in what is described by commentators as a 'utility death spiral'. However, many regulators see the value of DER and in New York the Public Utility Commission introduced the 'Reforming the Energy Vision' (REV) initiative, encouraging the network utilities to create markets for DER services and ensure that the utility retains a financial interest in Non-Wires Alternatives (NWAs) to grid infrastructure. A recent Con Edison project addressing the 'stacking' of multiple revenue streams for energy storage in New York to support both the distribution network and Independent System Operator will be examined. In California, driven by the prevalence of solar power and the consequent 'duck curve', the focus has

instead been on the consumer and addressing grid challenges through the latest IT solutions and architectures. The paper discusses Southern California Edison's Integrated Grid Project and the requirements that they see for DER integration solutions in the coming years.

In the UK, the problems of RE are more acute in system balancing, transmission congestion, voltage support and network capacity. While technical solutions have been the initial focus, the industry is in the grip of significant market and regulatory change to adopt RE fully into grid operations. New technical requirements, charging methodologies and DER services are all providing tools to ensure that the grid is fit for purpose. The 'Power Potential' project will be focused on, and how the roles of the System Operator, Distribution Companies, and RE operators are changing to provide new services to support grid stability.

Finally, Germany and the challenges of interconnection, transmission congestion, and rapidly rising customer bills will be examined. The '5% rule' and why EWE Netz has championed a recent change in legislation to enable a new model for distributed RE connection is discussed.

All of these projects will have relevance as India seeks to expand the contribution of RE to the energy mix. The paper will explore how the experience and learning from these international projects can be applied and prioritized to the Indian case, supporting the integration and operation of high RE volumes.

## II. NORTH AMERICA

In New York State the REV initiative has been encouraging innovative developments in the energy industry. The REV initiative partners with a comprehensive energy strategy for New York to:

- Help consumers make more informed energy choices;
- Develop new energy products and services;
- Protect the environment while creating new jobs and economic opportunities [1].

This is driven by changes in the industry including the reduction in cost of renewable energy technologies, continued innovation and a desire to allow more market participants into the energy system. As with many developed nations, there is a drive to connect more and more distributed generation to reduce demand charges, grid infrastructure is aging, and extreme weather events are occurring more frequently.

The state energy plan outlines the following targets, and REV demonstration projects are leading the way to meeting them:

- 40% reduction in greenhouse gas emissions from 1990 levels;
- 50% generation from RE sources; and
- 23% decrease in energy consumption from buildings from 2012 levels [2].

#### A. Con Edison – Stacking Revenue Streams

As part of a committed response to the REV initiative in New York, Con Edison are endeavoring to tackle some of the most significant barriers to the deployment of energy storage in New York state with their Stacking Revenue Streams project. These barriers are summarized as:

- Limited customer participation and market size;
- Lack of incentives for smaller system sizes suitable to cities; and
- Lack of coordination between battery dispatch and grid peaks.

Currently, energy storage developments are delivered by end users with a desire to reduce their peak demand, and in turn reduce their outgoings on energy. The energy storage development is limited in its size due to the customer's load profile and peak demand, therefore the benefit to the network is limited. In these Behind-The-Meter (BTM) cases the battery does not directly provide any benefit to the utility or provide grid support, but the end customer sees the benefit in saving money on energy.

This mismatch between the economic drivers for (BTM) energy storage projects and the needs of the wider distribution grid results in developers pursuing smaller projects, with the overall effect of increased costs on a \$/MWh basis and a decrease in the utilization of the storage assets for grid services. Similarly, the majority of end customers do not have a detailed knowledge of the tariffs available to fully understand or realize the full value of their BTM DER. This directly impacts on the number of customers that pursue energy storage developments and the size of the development.

Storage assets are capable of delivering multiple revenue streams, including the deferral of grid investment, avoiding the development of 'peaker plants', improving reliability, and much more; however, the market currently operates to procure these services in isolation and prevents the device being used for mixed purposes. In an ideal financial arrangement the utility would be able to pay only for a portion of the battery's costs, and only for batteries in locations beneficial to grid operation. Third party entities would therefore see the value in developing the assets and

provide the capital and location to develop the battery to participate in multiple markets.

This project is proposing to address these challenges through a Front of the Meter (FTM) arrangement. This arrangement provides Con Edison with access to energy storage dispatch schedules in order ensure their contributions to the grid are providing the maximum benefit. In order to have access to the dispatch schedules, Con Edison pays a set quarterly fee to the owner of the energy storage development. The owner is then also able to participate in other grid services and earn revenue. The benefits from this solution are:

- More customers will be able to invest in energy storage, and better understand the value of developments.
- The cost of deploying energy storage is minimized for the utility.
- The size of the market will increase as larger-scale development will be sited in locations suitable for grid support. This removes the restrictions typically seen for BTM sites which rely on host customer load profiles and energy demand.
- The interests of the utility, ratepayers, and third party service providers are better aligned through the new FTM dispatch agreement, which allows priority access for the utility during peak load.

The defining characteristics of this project come from the fact that the utility does not own the batteries being deployed. These are third party owned, with the utility being able to access their services when peak load reduction is required. The batteries are then also capable of accessing additional market services by 'stacking' revenue streams and enabling energy storage to be developed cost effectively.

#### B. Southern California Edison – Integrated Grid Projects

In California the utilities are experiencing an increase in the number of connections of PV and energy storage, driven in part by a desire to reduce demand charges and encouraged by the utility to develop in certain locations to help address peak loads. The consequence has been a dramatic change in the load profile to a 'duck curve' where PV contributes significantly to address summer day time peaks but leaves residual peak in the evening and then reverse power flow problems in winter when peak demand falls. Furthermore, even when these resources are connected to the grid it is not possible to realize their full potential since they are not integrated into the operation of the grid. Increasing DER integration with the grid poses a number of challenges such as the provisioning of reliable and robust communication and control systems, the implementation of interconnection rules, and the impact on grid planning. These are the challenges which have led Southern California Edison to embark on the Integrated Grid Project (IGP), which aims to promote the integration of DERs through a multifaceted approach of various Non-Wire Alternative technologies.

A key part of IGP is the utilization of a Distribution Control System (DCS) which leverages ANM technology to

control DER behavior. The DCS operates as a real-time, end-to-end control and dispatch platform that provides constraint management and DER coordination against multiple constraints and optimization goals.

The DCS carries out a number of key functions such as:

- **Constraint Management:** Facilitating the coordination of DER dispatch from schedules or higher level systems with real-time set-point control for measured constraints. This ensures that the various grid parameters such as voltage and thermal are kept within safe limits and reduce the need for grid augmentation.
- **Optimization & Scheduling:** Focusing on the generation of optimal DER schedules to maximize utility and customer benefits while minimizing costs, based on Volt-VAr Optimization (VVO) and Optimal Power Flow (OPF) applications. This helps to reduce technical losses and minimizes power consumption.
- **DER forecasting:** Hourly day-ahead DER, including Distributed Generation (DG), load & Energy Storage Systems (ESS) with forecasting based on weather, geospatial, and economic drivers to ensure resources can be used to their full potential across multiple operational use cases.
- **Virtual Microgrid Controller:** This performs local control of DER as a sub-system within the overall control hierarchy, in order to maintain near zero power flow at a specific point on the grid to improve reliability.

The DCS operates as a testbed within a laboratory environment with an aim to deploy into production on the Southern Californian grid. This project demonstrates a reference IT architecture with multiple systems effectively utilizing a shared data space and removing the common utility problem of siloed data sets. The project shows how the DCS provides necessary DER control capability not available through SCADA / DMS systems and provides a roadmap for future integration frameworks.

### III. UNITED KINGDOM

The UK has set renewable energy and carbon emissions targets which it has been striving to meet in recent years; 15% of energy from renewable sources [3] and 80% reduction in greenhouse gas emission from 1990 levels [4]. The regulator in the UK, Ofgem, introduced the Low Carbon Network Fund to encourage innovation in the energy sector to help achieve these targets.

The grid infrastructure in the UK is aging and saturated at transmission level, resulting in costly and lengthy connections processes for new generation wishing to connect with new transmission infrastructure taking many years to develop and construct. These challenges prompted generation developers to develop smaller scale sites connecting at distribution level, rather than large, centralized plant connecting to transmission infrastructure. The continued growth in generation connecting at distribution level has led to the emergence of distribution network constraints.

Active Network Management (ANM) and managed connections have provided an effective solution to grid augmentation, by allowing the real-time control of generators against known network constraints. They result in cheaper and faster connections for generation developers, helping to meet the renewable energy targets.

Regulation and the structure of the energy industry is changing in the UK, with the transition from Distribution Network Operator (DNO) to Distribution System Operator (DSO) concept gaining momentum. This will see DNOs becoming more active in their operation of the networks, working together with the System Operator (SO) to maintain a safe a reliable electricity grid, and facilitating market participation for all customers, demand, generation, and energy storage alike.

#### A. National Grid - Power Potential Project

The South East of the U.K. is the ideal location for additional interconnectors and renewable generation, however the state of the transmission system there limits the opportunities available. Ageing infrastructure and saturation of the network result in the requirement for extensive transmission system reinforcements to accommodate new interconnectors or new renewable generation.

National Grid is leading the Power Potential Project (formerly TDI 2.0), funded through the Network Innovation Competition fund from Ofgem, and is targeted at addressing these issues. The main aims of the project are to:

- Develop a whole system approach to implement smart solutions as cost effective alternatives to network reinforcement.
- Develop both technical and commercial solutions to maximize the benefit that DER can provide for the transmission system.
- Develop a DSO route to market for such solutions in a coordinated manner with existing System Operator functions.

UK Power Networks (UKPN) is the DNO working with National Grid on this project. They have experience of providing managed connections for generators via ANM and have explored the potential benefits that energy storage could provide for the DNO. This experience will be drawn upon in this project, as ANM is able to mitigate constraints while maximizing the generation that can be connected in a particular distribution network. In this project UKPN will act as a route to market for reactive power services from DER to the SO. They will also facilitate the coordination of DER to benefit the SO, and present the availability and cost for services from each of the participating Grid Supply Points (GSPs).

This approach will provide an additional resource for National Grid to access for managing the transmission system, and the project will provide an environment to test the technical capability and coordination required to operate in such a fashion where both the SO and the DSO require flexibility.

The required solution will be based upon IT and communications technology to allow the interaction between all market participants. This is essential so that in

the event of the SO requiring a particular response, it is able to see that response coming from the distribution system. Likewise, the DNO must be able to see what opportunities for services are available. New commercial arrangements will be explored and developed between DER operators, UKPN, and National Grid. The main services outlined are reactive and active power support for transmission system voltage support and re-dispatch of generation respectively.

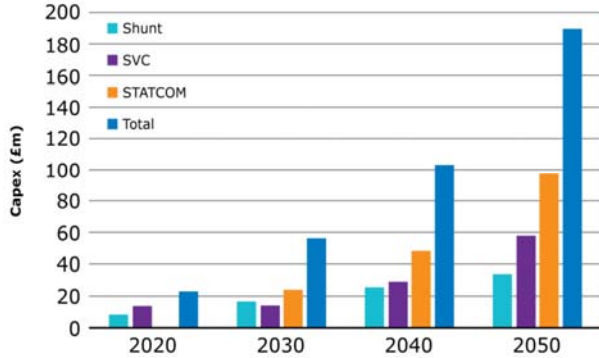


Figure 1: Business as usual CAPEX

The benefits case for taking an innovative approach is evident in Figure 1 and Figure 2. The image in Figure 1 shows the increase capital expenditure required to maintain the transmission system if traditional methods are followed. When compared with expected costs associated with the innovation project, Figure 2, it becomes clear that there is a direct financial benefit from utilizing distribution resources for transmission system support [5].

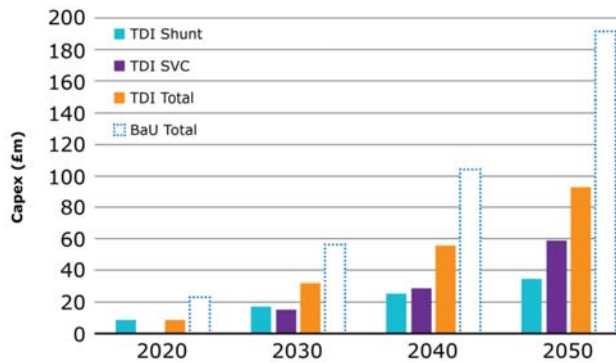


Figure 2: Power Potential project CAPEX

#### IV. GERMANY

Previous legislation in Germany stated that the electrical grid must be able to accommodate energy produced from renewable sources in its entirety, with real power curtailment of renewables strictly limited to when there was no alternative for keeping the network in a safe operating state. The growth of DER at distribution level led to delays in connecting projects to the grid and spiraling electricity bills to pay for the grid augmentation.

As with power systems planning in other geographies, the typical planning approach follows the worst case scenario meaning that there is inherent unused capacity as the network is constructed for a situation that may only occur for a few hours per year. This prompted the following questions to be asked:

- Does it make economic sense to construct a grid for conditions that occur so rarely?
- By what percentage could connection capacity be increased if the grid did not have to account for the worst case scenario?
- What is the economic balance when substituting grid augmentation for capacity growth through curtailment?

EWE Netz endeavored to address these questions in their study and subsequent trial investigation curtailment to increase hosting capacity for renewables.

##### A. EWE Netz – 5% Rule

EWE Netz, a network operator in Germany, pioneered the 5% rule, the theory of which being “the load flow dependent throttling of a low percentage of yearly feed-in carried out in maximum load situations leads to a drastic increase of grid connection capacity” [6].

The load flow dependent throttling of generation, or curtailment, is the key characteristic of the 5% rule, however the impact on voltage stability and equipment does limit the generation that can be curtailed. With this in mind the design of a system was created considering the following aspects:

- Monitoring all critical components in the network;
- Reactive power control potential;
- Load flow calculation;
- Sensitivity of system variables to generator feed-in;
- Generator curtailment.

The impact of generator curtailment was simulated using time series analysis for a year’s worth of load and generation data in 15 minute time steps. The analysis provided the results shown in Figure 3.

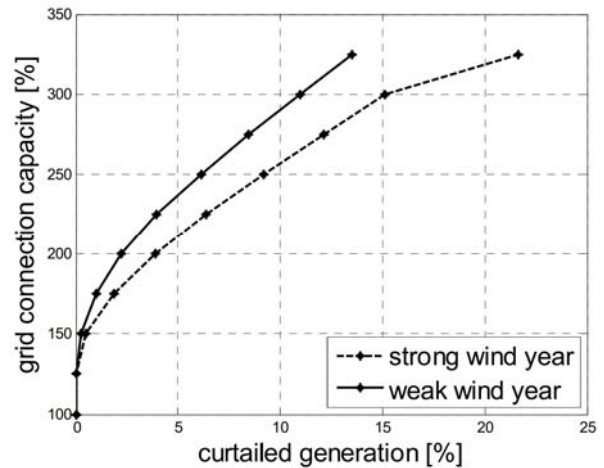


Figure 3: Connection capacity against curtailed generation

This shows that at 5% curtailment of generation, the connection capacity could be increased by 200%, with this increasing if further curtailment is to be accommodated. This approach was then field tested in Germany, and has subsequently resulted in a change in the legislation around curtailment of generation whereby 3% of all distribution connected generation is permitted to avoid grid augmentation. Such curtailment is compensated.

### 1) *Project Enera*

This has now been taken further with the Enera project which is driving the changes required to introduce new technologies and market mechanisms in the energy sector. It is introducing a “traffic light” system for the grid and generation to indicate, in advance, if curtailment is required [7].

In the green traffic light phase, which represents the grid in a healthy operating state, generation is not curtailed, but the network operator is able to make use of reactive power control for reactive power optimization at the transmission boundary. In the yellow traffic light phase congestion is expected in the network, and in this phase market mechanisms will be available for generators to participate in and potentially alleviate the anticipated congestion. In the red traffic light phase the network operator is capable of using active power control to maintain safe network operation.

The project is part of the German Federal Ministry of Economics and Energy and is aiming to develop scalable solutions for the large scale use of renewable energy focuses on the application of smart grid technology.

## V. DISCUSSION

For India’s energy market and the custodians of the power infrastructure, a challenging period of change lies ahead led by the Government’s ambitious target for renewable penetration and the transition to electric vehicles.

The complexity, magnitude, and rate of change required exposes traditional methods of planning for network reinforcement and grid connections to be prohibitively costly and impractically slow.

Observations from other markets already addressing similar challenges show that while the priorities and constraints may vary, the similarities include introducing (initially counter intuitive) controlled flexibility of power balance and energy flows across commercial boundaries. This is achieved by implementing elegant technical solutions in context of innovative regulation and commercial agreements.

The changes that have been seen in North America come from a requirement to effectively manage peak load. In New York space is limited and at a premium yet by encouraging energy storage developments and spearheading innovative commercial arrangements, it is possible to avoid investment in a new substation and associated costs and exploit storage for the benefit of the wider grid. This would not be possible without the support and backing given by the New York State REV program which is embracing new technological and commercial methods for improving the network. In California the massive uptake of PV generation has resulted in a mismatch between supply and demand, and a desire to find ways of connecting generation without having to build grid so that the full potential of renewables can be realized. The use of NWA and integrated grid planning mean that using DER at the distribution level is common in North America to mitigate technical problems, particularly load growth. In India, this most immediately translates to using DER to reduce technical losses through

reactive power management. Our initial analysis of urban and rural case study networks suggests huge potential to reduce reactive power losses because of the highly inductive nature of load.

In Germany, the 5% rule was pioneered by a network operator, and from successful simulation and trial, changes in legislation have been made surrounding the curtailment of generation to increase hosting capacity. In-feed management, to allow compensated curtailment by the SO for system stability concerns, has been in place for some time now, and it relies on forecasting and scheduling of thermal plant based on renewable forecast. Germany, however, is situated in the heart of mainland Europe, is very well inter-connected and therefore finds it relatively easy to export excess generation. That is more difficult in India, particularly the south, which has limited interconnection. The use of forecasting, with inherent forecasting error, has led to over-curtailment of generation, which is compensated in Germany, resulting in increased customer bills. With limited system reserve, a lack of flexible ‘peaker plants’ and more variable weather patterns this approach applies to India but likely requires a more granular, real-time approach, to minimize curtailment. This must be considered while India is still forming its curtailment compensation policies.

In the UK, the national regulator Ofgem encourages innovation in the networks through the Low Carbon Network Fund that has now been replaced by the Network Innovation Fund. This has resulted in new technologies and commercial processes being adopted after trials in a business-as-usual fashion. ANM is perhaps the best example of this, and there are now 14 operational schemes across the UK actively controlling DER, batteries, and domestic demand. The first incarnation of ANM in the form of Special Protection Schemes (SPS) proliferated and are increasing deployed and more active as system balancing becomes more challenging with increasing renewable penetration levels. ANM can significantly reduce the impact of SPSs, reduce curtailment, and make sure the SPS does not operate. This concept has been demonstrated in the Orkney ANM scheme [8] where hosting capacity was doubled, saving over £30m in avoided grid augmentation. In the UK it is very difficult to construct transmission lines and it can take a very long time. This has resulted in commercial developers of projects opting to connect at distribution level where the connection costs and project timescales are less. This has created technical problems in distribution networks that can be mitigated very cost effectively with a small amount of curtailment. Introducing this too late and without a consistent approach (whether curtailment is compensated or not) has hampered the ability of the UK industry to reap the benefit from the innovation they pioneered. India does not have this problem at the moment with central planning of generation and reverse auctions to construct the generation capacity, but it may well soon. With reducing PV costs and customers increasingly turning to renewable technology to reduce energy costs the connection of these devices in the distribution networks will inevitably result in the same situation. India should look to learn the lessons from the UK and ensure a consistent policy for DISCOMs to apply such methods.

In India, with each state and region operating semi-autonomously the State Load Dispatch Centers (SLDCs) have a requirement to balance generation and demand. While they are highly interconnected and therefore have inertia in the system, they have very inflexible existing generation in many states, with long ramping times, meaning that in effect there is very limited reserve capacity. Much of the thermal plant have technical limitations, the merit order for control is based on price only, and scheduling is a manual process. The Renewable Energy Management Centers (REMCs) intend to move towards more sophisticated scheduling but this will not resolve the issues surrounding forecasting error which, in a state with little flexibility or ability to export, can mean very substantial curtailment or load shedding. Countries like the UK have increasingly taken the approach that the method to minimize curtailment is to ensure that renewables can run free but with the correct control infrastructure, such as ANM, in place to throttle back generation when constraints (capacity, voltage, reactive power, system reserve, etc.) are active.

## VI. CONCLUSION

What is suggested for the India market in order for it achieve the ambitious RE integration targets and maintain safe operation of the network is to draw on the international experience presented here. DG and DER can be used as part of a strategy to reduce technical losses in networks and can be very flexible resources to avoid grid augmentation and support grid operations. They are already used in other geographies for constraint mitigation and mitigating peak load, and can be part of a toolbox for India to reduce losses experienced in the network. The REMCs have an opportunity to learn from the German in-feed management program, and implement more sophisticated schedules to try and reduce forecasting error as much as possible; however, this presents a requirement for fast acting, responsive, and autonomous control, such as ANM, that can minimize the curtailment of RE. This can provide a controllable buffer for the SLDCs, and reduce the occurrence of SPS operating.

The Distribution Companies must realize that although RE at distribution level is not an issue for them now, if India follows other international trends then RE developers will move to seek distribution connections when connection at transmission level becomes too costly or time consuming.

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