Shape of the future power grid: Grid connection challenges

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SUMMARY

Growing worldwide concerns, that pollution makes climate change worse, reinforce the global mandate to develop and invest in clean energy sources. The need for reduction in carbon emission together with growing electricity demand has significant implications on the shape of the future power grid.

The move to renewable generation, with remote/small projects, means that the associated electricity networks also need to be expanding their reach, capacity and flexibility. The quality and quantity of renewable generation make it difficult for the power system to readily accept and dispatch the same in the electricity market. The remoteness of a new generation site may require significant grid connection investment and in some instances make the project commercially uneconomic.

While economic measures such as carbon taxing are added incentive for generators to consider sources such as wind, biomass, solar and others, a key issue that needs to be addressed is how to ensure an efficient mix of transmission investment to ultimately provide the lowest delivered cost of energy to consumers.

Some of the options to facilitate connection of renewable generation in the future are:

- Build new infrastructure: Considerations are power quantity, quality, security of supply, grid asset security, environmental impact and public resistance to new lines
- Develop Energy Storage Systems (ESS) to mitigate the variability of wind and solar generation
- Implementing new technology that can optimise use of existing assets i.e. Smart Grid

This paper discusses some of the key factors that have an impact on future electricity networks and looks at a possible solution that can shape the future electricity grids.

A novel concept of a “Grid Collection Point” (GCP) has been considered in this paper. The GCP substation will collect generation from a diverse range of sources to offer a more economic cost-share solution to individual generators in terms of transmission costs and power quality improvement facilities. It is through the diversity of generation and the use of Energy Storage Systems that a GCP can present a single, more reliable and quality source of electricity for connection to the grid.

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KEYWORDS
Renewable Energy, Grid Collection Point, Energy Storage Systems

1. RENEWABLE ENERGY – GLOBAL AND REGIONAL GROWTH

The growing impetus for electricity to be sourced from renewables is reflected from a recent United Nations Environment Programme (UNEP), Division of Technology report stating that the global investment in renewable power in 2010 was up by 32% on 2009 to $211 billion.

In Asia promoting clean renewable energy is one of the Asian Development Bank’s (ADB) highest priorities. In 2010 it invested $1.8 billion in clean energy, exceeding its $1 billion target for the third year in a row. From 2013, the target will rise to $2 billion a year.

The Indian target is to quadruple renewable energy generation to 72,400 MW by 2022.

Presently, ninety percent of Thailand’s energy is from natural gas, coal and lignite. It is planned that by 2021, 20.4% of energy will be from renewables i.e. a sharp rise from 1750 MW to 5608 MW. ADB is funding projects such as the 73 MW solar project in Lopburi and 38 MW project in Ayutthaya.

Following the inevitable growth in generation capacity the associated transmission networks also need to be expanding both their reach and capacity. The different sources of electricity generation have their own unique advantages and disadvantages relating to its impact on the grid. The quality and quantity of renewable generation make it difficult for such generation to be considered as readily dispatchable. Table 1.1 details typical characteristics of various types of renewable energy generation.

Table 1.1 Renewable Generation Characteristics

<table>
<thead>
<tr>
<th>Source</th>
<th>Generation capacity</th>
<th>Limitations</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>No limitations</td>
<td>Suitable sites</td>
<td>Well developed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental impact</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>No limitations</td>
<td>Suitable sites</td>
<td>Advanced development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intermittent</td>
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<tr>
<td></td>
<td></td>
<td>Weather dependent</td>
<td></td>
</tr>
<tr>
<td>Solar</td>
<td>Small 1 kW installations to large solar parks</td>
<td>Intermittent</td>
<td>Advanced development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weather dependent</td>
<td></td>
</tr>
<tr>
<td>Geothermal</td>
<td>No limitations</td>
<td>Suitable sites</td>
<td>Well developed</td>
</tr>
<tr>
<td>Tidal</td>
<td>Limited – trial generation</td>
<td>Intermittent</td>
<td>Under development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weather dependent</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>Small – limited to local consumption</td>
<td>Availability of basic fuel source</td>
<td>Under development</td>
</tr>
</tbody>
</table>

The grid connection requirements of different generation sources have significant implications for the nature of power transmission. Therefore the drivers for future transmission lines may be different from the conventional “bulk transfer of power”. The move to renewable generation with remote and small projects or larger nuclear/conventional fossil fuel projects means that the network will be required to collect such generation and transfer it to the load centres.

In this paper the following three renewable generation scenarios have been considered for the evaluation of their impact on the electricity network (distribution or transmission).

1. Remote “Islanded” generation
2. Embedded Generation
3. Remote “Grid Connected” Generation
2. ENERGY STORAGE SYSTEMS

Due to the variable nature of renewable energy generation from sources such as wind and solar, the development of devices for storage of electrical energy is perhaps the most significant challenge to the industry. Such devices will assist in levelling out the variations to the generation thereby making it more predictable and readily acceptable to the grid. Research and development work is being undertaken right across the world with agencies such as the Electric Power Research Institute (EPRI) running programs that have a vision to provide the industry with large scale energy storage systems. The program will also evaluate efficiencies and cyclic performance capabilities of Energy Storage Systems. Some of the recent developments in Energy Storage Systems technology are as follows:

**ABB – Battery Energy Storage System**
ABB are installing a Battery Energy Storage System (BESS) at Fairbanks, Alaska. The BESS will be able to automatically pick up 26 MW of load for 15 minutes (or 40 MW for 7 minutes). The installation comprised of a series of connected battery modules.

**Australian National University – Thermochemical Storage System**
The ANU group is currently experimenting with an ammonia based solar energy storage system. The storage system heats ammonia to 750°C, using solar energy, to dissociate the ammonia into its component gases hydrogen and nitrogen, and when combined back into ammonia, the high heat levels given off can be used to super-heat steam (when the sun isn’t shining).

3. REMOTE “ISLANDED” GENERATION

This comprises of small to medium sized generation required to service remote communities that are not connected to the grid. In Queensland (Australia) such generation can typically range between 300 kW to 2 MW. As this generation is not connected to the grid it is also termed as “Off-Grid Generation”

The Australian government has committed $300 million to renewable energy generation, but the 10.6 MW of solar, wind and micro-hydro will save 24 million litres of diesel. The key driver here is not growth in demand, but the reduction of green-house gas emissions and the carbon footprint.

**Challenges**
As such “Islanded” generation is not grid connected it obviously does not impact on the supply grid. However there are issues that will still impact on the local electricity assets.

As the key driver is only reduction of the carbon footprint, the major challenge will be to overcome the variable nature of the wind/solar generation.

**Solutions**
Install Energy Storage Systems.

4. EMBEDDED GENERATION

In the Australian context, this largely comprises of small solar PV installations between 1 – 5 kW. To encourage domestic solar PV installations the Australian government provides very high rebates to the users. Queensland alone has over 500 MW of installed solar capacity. In addition the feed-in tariff is $0.44/kWh as compared to a peak supply tariff of $0.25/kWh. These make it very attractive to the users. The objective again is the reduction of green-house gas emissions and the carbon footprint.

**Challenges**
The new solar generation connections will result in disturbance injection into the power system and possibly impact on the LV planned/permissible voltage disturbance levels.
If the cumulative generation for the new connections exceeds the permissible loading on the supply transformers or cables, the assets will have to be uprated to allow for the new generation.

While solar PV installations are potentially beneficial to the users, it has the potential of impacting the grid both in terms of voltage disturbances and asset ratings. The typical daily demand profiles/peaks are also changing as most of the residential customers are away during the day (when solar generation is at its peak) and then use power in the mornings and evenings when the solar generation is not available.

**Solutions**
Assess each new connection for its impact on the local network and approve only if the system is not compromised or assets do not require replacement/upgrades. However this is in contradiction to the results desired from the government’s initiatives.

Installation of Energy Storage Systems can help if the connections are isolated from the grid thereby making then “off-grid” connections.

5. REMOTE “GRID CONNECTED” GENERATION

A high level of renewable energy penetration into the grid does have an impact on the quality and reliability of the power supply. The issues are well understood by the industry and there is continuous technology advancement to improve the power quality and reliability specifically from wind generation.

The key driver in this scenario is the growth in electricity demand. The additional benefits achieved being the possible reduction in greenhouse gas emissions.

**Challenges**
Other than carbon credits, in countries such as Australia and New Zealand there are no incentives for the developers of wind generation. The remoteness of new sites can make grid connection costs significant and in most instances make the projects commercially uneconomical.

To meet increased demand, the growth in generation goes together with the growth of transmission infrastructure. Therefore planning for new generation without consideration being given to transmission and vice versa is not considered prudent. A key question is how to ensure an efficient mix of generation and transmission investment can be achieved to provide the lowest delivered cost of energy to consumers.

With large scale penetration of wind/solar generation additional “spinning reserves” will be required. Determination of the asset capability required of the related lines/equipment is difficult and could result in over or under building of capacity.

**Solutions**
Transmission initiatives will have to be taken to ensure that the grid connection costs do not rule out the establishment of new renewable generation.

Pooling of renewable generation to try to balance out the variable nature of such generation and developing grid connection solutions that present a more reliable and secure form of connection in terms of power system requirements.

Installation of Energy Storage Systems to reduce “spinning reserve” requirements.

A new concept of a “Grid Collection Point” (GCP) has been considered in this paper. The GCP substation will collect generation from various sources and presents a single, reliable and secure connection point to the grid.
6. “GRID CONNECTION POINT”: A NEW CONCEPT

Need for a Grid Connection Point
As mentioned earlier, it is beneficial if transmission network planners take the initiative in planning new generation plant within a power system. The formation of a “Grid Connection Point” (GCP) is a possible first step in meeting this objective.

Through a centralised/coordinated planning process, the regions with high potential for power generation should be identified. All stakeholders including the transmission network company can jointly agree on the location of a GCP substation for the region under consideration.

The involvement of these key stakeholders ensures that the transmission asset owners are fully aware of future generation scenarios and can allow for the same in their grid development plan. This also gives an opportunity for the transmission asset owner to discuss system constraints and possible connection configurations with the generation asset owners.

Grid Connection Point
The traditional concept of transmission and the conventional method of connecting new generation are shown in the first two line diagrams in the figure below.

The third single line diagram shows a Grid Collection Point (GCP) substation.

Benefits of a Grid Connection Point
This substation will provide a single point of connection to the grid and serve as a balancing point for various types of renewable generation combined with base load stations, where possible.

The facilities at this substation can also include centralised power quality improvement equipment. In addition the installation of an Energy Storage System at this substation will have a complementary effect on the reliability and quality of power being injected into the grid.

Capital cost sharing between the generators and the transmission asset owners may make such a grid connection more economical as well as present a better proposition from a power system control and protection perspective.
7. IMPLEMENTATION: GRID CONNECTION POINT CONCEPT

The author had raised the concept of a “Grid Connection Point” in November 2007 at the E21C Conference in Sydney. The validation of this concept is demonstrated through several ADB funded projects in India such as the Charanka Solar Park – “POOLING SUBSTATION” and the Himachal Pradesh Clean Energy Transmission Investment Program (HPCETIP).

Both these projects are transmission initiatives to facilitate effective power evacuation from the regions and provide shared assets to power developers within the region.

8. CONCLUSIONS

It is definitely possible to connect new renewable energy sources to the grid. However, until such time significant developments as mentioned above eventuate, future grid developments will comprise of a mix of new extensions and upgrades of existing networks. It is also possible that economic or power system considerations may in some instances act as an impediment to new renewable energy generation projects.

The development of Energy Storage Systems technology will be a significant factor in facilitating renewable energy generator connection to the grid.

If the growth in electricity demand is a key driver for new renewable generation then it is imperative that grid development initiatives will have to precede generation investment.

The installation of a “Grid Collection Point” substation can be a compromise for investment initiatives between generation and transmission asset owners. From a power system perspective a “Grid Collection Point” can act as a balancing mechanism between different sources of generation and in conjunction with Energy Storage Systems act as a single, reliable and predictable point of connection for new generation.

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Short Bio-data of Anurag Gupta

Anurag is a Technical Director (Energy) in Aurecon’s, Brisbane office. He has 33 years of experience in the industry during which he gained expertise in design, construction supervision and project management of EHV substation projects. He obtained his BE (Electrical) degree in 1978 and Project Management Professional (PMP) Certification in 2007.
Shape of the Future Power Grid
Grid Connection Challenges

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Industry Environment

Global concern over green-house gas emissions from conventional fossil-fuel electricity

Greater impetus for electricity to be sourced from renewables, including self generation
Introduction / Industry Environment

The global credit crunch has impacted utilities: Will investment be available to keep pace with future demands?

**Aging Assets**

Aging electrical grids due for overhaul

Overtaxed power assets

Obsolete technology

Supply **SECURITY** and **RELIABILITY** are key to the **MODERN GRID**
Global Electricity Generation/Demand

World Energy Consumption by Fuel 2007-2035

Growth in World Power Generation and Consumption 1990-2035
Australia Renewable Energy - Map

- **Solar**
- **Wind**
- **Geothermal**
- **Landfill Methane**
- **Water**

Australia electricity demand growth < 5%
Renewable Energy growth target ~ 1200 MW/year up to 2020
United Nations Environment Programme (UNEP) Division of Technology
- Global investment in renewable power in 2010 was up by 32% on 2009 to $211 billion.

Asia - Promoting clean renewable energy is one of the Asian Development Bank’s (ADB) highest priorities. In 2010 it invested $1.8 billion in clean energy. From 2013, the target will rise to $2 billion a year.

ADB Vice President - Asia must expand solar energy generation to stay on its economic growth path and reduce carbon emissions.

Thailand - It is planned that by 2021, 20.4% of energy will be from renewables i.e. a sharp rise from 1750 MW to 5608 MW. ADB currently funding: 73 MW solar project in Lopburi and 38 MW in Ayutthaya.

India - Target is to quadruple renewable energy generation to 72,400 MW by 2022.
# Renewable Generation: Characteristics

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<th>Technology</th>
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<tbody>
<tr>
<td>Hydro</td>
<td>No limitations</td>
<td>Suitable sites, Environmental impact</td>
<td>Well developed</td>
</tr>
<tr>
<td>Wind</td>
<td>No limitations</td>
<td>Intermittent, Weather dependent</td>
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</table>
Grid Connection Challenges

In this paper/presentation both the transmission and distribution level networks have been considered. Some of the typical generation scenarios are:

**Remote “Islanded” generation**
Small to medium sized generators to service remote communities. Does not impact on the electrical network. Also termed as “Off-Grid Generation”

**Embedded generation**
Mostly small generation installed at the distribution level. This impacts on local distribution networks.

**Remote “Grid Connected” generation**
Generation that is remote from load centres. Size of generation can vary significantly. This impacts on the transmission systems.
Remote “Islanded” Generation

Australian Government: Renewable Remote Power Generation Program (RRPGP) $300 million committed to renewable energy generation.

Does not impact the grid but 10,600 kW of solar, wind and micro hydro will save 24 million liters of diesel fuel each year.

**Challenges:** Address impact on installed plant capacity
Demand side management

**Possible Solution:** Energy Storage Systems
Energy Storage Systems

As more renewable energy sources are integrated into the grid, energy storage can become instrumental for micro and smart grids.

Energy Storage Systems (ESS) - Energy-dense batteries with bi-directional, grid-tied inverters and communications systems to allow interface with the electrical grid.

Besides grid stabilisation and load leveling, ESS potentially provide back up power, especially when solar/wind is not available. Electric Power Research Institute (EPRI) are evaluating efficiencies and cyclic performance capabilities of ESS.
Energy Storage Systems

**ABB** has designed and installed a Battery Energy Storage System (BESS) for Golden Valley Electric Association (GVEA). BESS has the ability to pick up 26 MW of load for 15 minutes (or 40 MW for 7 minutes).

**Australian National University** is researching a system in which ammonia (NH₃) is dissociated in an energy storing (endothermic) chemical reactor as it absorbs solar thermal energy. At a later time and place, the reaction products hydrogen (H₂) and nitrogen (N₂) react in an energy releasing (exothermic) reactor to resynthesize ammonia.
Embedded Generation

Typical Solar PV - 1.5 to 5 kW.

Australian Government rebates/incentives has assisted home owners to make a move to solar power.

Queensland alone has 500 MW of installed solar capacity.

Feed-in tariff of 44 cents per kWh as compared to peak tariff of 25 cents per kWh (in Queensland).
Embedded Generation

**Challenges:**
- Voltage disturbances in the system
- Stresses the system and upgrades necessary to match capacity
- Manage changes in consumption pattern resulting in sharper peaks

**Solutions:**
- Assess applications for connections
- Energy Storage Systems
Remote Renewable Generation

Remote generation
Generation that is remote from load centres. Size of generation can vary significantly. This impacts on the transmission systems.

- New generation is located in relatively remote areas requiring long transmission connections to connect to the grid.
- This becomes a negative incentive for developing small generation projects.
- Designing grid extensions to accommodate renewable generation, specifically wind poses problems arising from large sudden changes, variability and unpredictability of output.
- Difficult to establish asset capacity ratings and could result in over building of capacity.

To mitigate some of the above it is proposed that such generation be collected at a “Grid Connection Substation” *

Remote Renewable Generation

Challenges:
- Providing incentives/facilitation of connection of remote renewable generation
- Power transmission costs associated with long transmission lines
- Provision of spinning reserves
- Impacts on the grid in terms of offload cycles and investments in assets
- Beyond the generation substation - Are contributions towards carbon footprint actually reduced?

Solution:
Grid Connection Substation *
Grid Connection Challenges

Convention:
Power is conveyed through the transmission network to grid exit points, then to consumers through distribution substations.

Collection Substations:
New substations, at strategically planned locations on the grid, that effectively act as collectors for generation from new sources.

Advantages Collection Substations can offer:
• Single connection point to grid rather than multiple breaks in the grid
• Better control of power quantity and quality through consolidation of generation
• Possible sharing of grid connection costs between generators. Additional incentive for small/renewable generation.
Grid Connection Challenges

Conventional Connection: New Generation

Collection Substations

Shape of the Future Power Grid
AORC Technical Meeting - October 2011
Industry Initiatives

India
Several projects to support solar power development in a “cost-effective” manner.
Reliable evacuation system for the Charanka Solar Park:
Creation of a 66/220/400 kV **POOLING SUBSTATION**
Additional bays at 220 kV and 400 kV remote substations
109 km of 400 kV lines, 107 km of 220 kV lines and
600 km of 66 kV underground interconnections between power developers.

Himachal Pradesh – Strengthening of existing and building of new infrastructure for effective power evacuation – ADB supported project: Himachal Pradesh Clean Energy Transmission Investment Program (HPCETIP)
Conclusion

In conclusion:

Depending on its location and size, connection of renewable generation to the grid is definitely possible, though at present, it may be economically disadvantageous to the generators unless suitable power evacuation infrastructure is available.

In countries such as Australia, a healthy balance needs to be achieved between the installation of small embedded generation (solar) and the consequential upgrades to the distribution assets.

Development of storage devices will be an ideal solution to balance the variable nature of generation from sources such as wind and solar.
Conclusion

The economic viability of long distance transmission for connection to large remote renewable generation can be far more attractive to the generators through an approach of cost sharing through:

“GRID COLLECTION SUBSTATIONS”

These substations also offer a more reliable, quality and secure connection to the grid from a power systems perspective.

Which initiatives should come first: Generation or Transmission?

Through this presentation, it can be concluded that it is definitely:
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