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Smart Grid:

key concepts and challenges with the integration of solar energy

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What is Smart Grid?

There is no universally accepted definition of smart grid, but here is a reasonable one.

http://knowstartup.com/wp-content/uploads/2016/01/knowstartup-smartgrid1.png

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

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What is Smart Grid?

- Smart grid is an **evolving vision** of the future of power systems
- It is impossible to upgrade national power systems in a short time due to their immense scale and complexity

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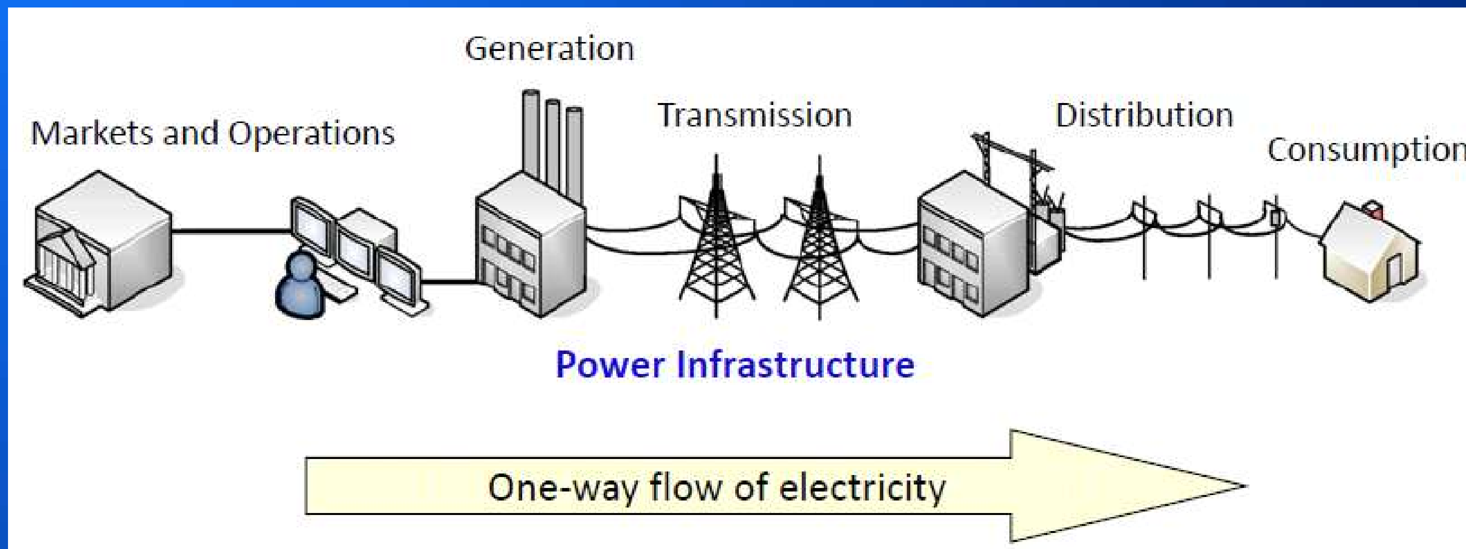
Traditional power grid



Centralized, bulk generation
Heavy reliance on coal and oil
Limited automation
Limited situational awareness
Consumers lack data to manage energy usage

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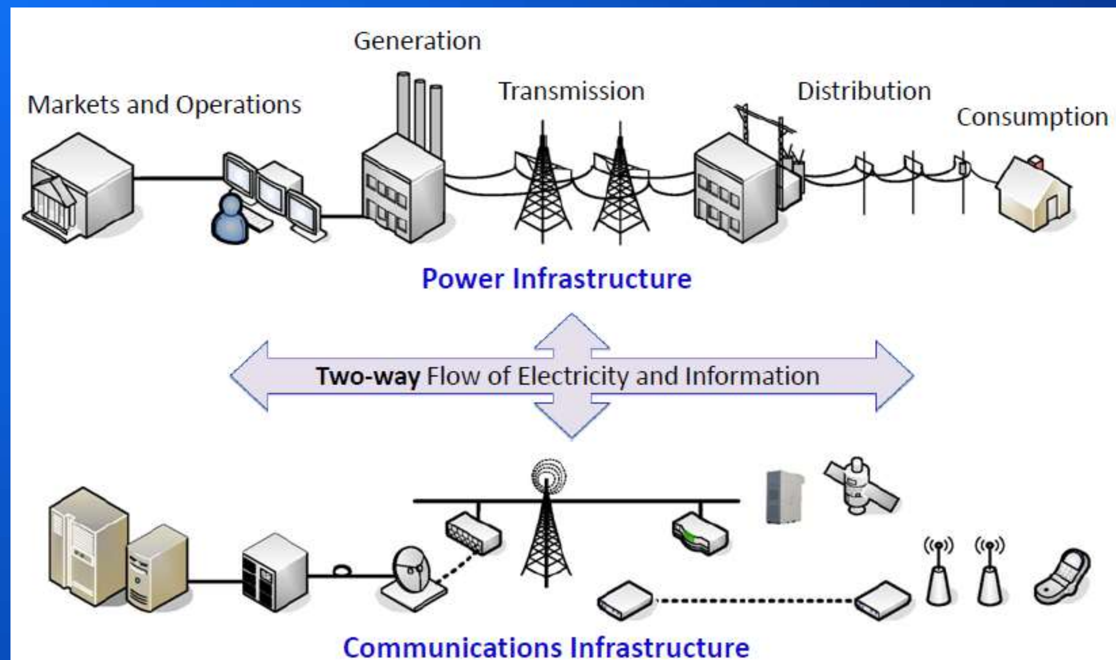
Smart grid



Distributed generation

Extensive use of renewable energy sources

Widespread automation

Much better situational awareness

Consumers are informed and actively participate

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Smart grid drivers

- **Ageing infrastructures:** *Large parts of the existing infrastructure dates back to the 1960s or earlier. Equipment is under stress during peak demand.*

Source: http://www.army.mil/e2/c/images/2012/11/12/271638/size0.jpg

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Smart grid drivers

- **Integrating intermittent energy sources:**
  - *This causes additional strains on existing grids.*
  - *Their intermittence must be counter-balanced using appropriate technologies*

http://www.telezones.com/wp-content/uploads/2015/02/Earht-4-Energy-Review.jpg

[redacted]

Smart grid drivers

- **Security of supply and increase in energy needs.**
  - *Efficient and reliable electric power system is fundamental to maintain functioning economies and societies.*
  - *Electricity demand is steadily increasing.*

http://www.smart-kit.com/wp-content/uploads/2012/11/power-outage-puzzle.jpg

[redacted]

Smart grid drivers

- **Sustainability:**
  - *Pressure to reduce CO_2 emissions through the adoption of clean energy sources and increasing energy efficiency.*

http://www.adlittle.com/uploads/pics/sustainability_06.jpg

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Smart grid drivers

- **Lower energy prices:**
  - *Regulators are pushing for more competition to lower energy prices.*
  - *Utilities need to add information and communication techniques to maintain profitability and retain the ability to invest*

http://blog.cleanenergy.org/files/2014/05/lower-energy-bills-graph.jpg

http://consumerenergyalliance.org/cms/wp-content/uploads/2015/07/high-electricity-bill.jpg

[redacted]

Smart grid drivers

- **Need by utility companies to address these challenges:**

  1. High power system loading

  2. Distance between generation and consumption

  3. Growing share of intermittent renewables

  4. New consumption models (e.g. electric cars)

  5. Growth of distributed generation

  6. Transparent consumption & pricing

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Benefits of the smart grid

1. **Improving power reliability and quality**

http://media.cmgdigital.com

[redacted]

Benefits of the smart grid

2. **Minimizing the need to construct back-up (peak load) power plants**

https://www.clp.com.hk/en/about-clp-site/power-generation-site/infrastructure-and-fuel-mix-site/PublishingImages/Black%20Point%20Power%20Station%20(Medium).jpg

[redacted]

Benefits of the smart grid

3. **Enhancing the capacity and efficiency of existing electric grid**

http://cleandisruption.com/wp-content/uploads/2015/06/smart-grid.jpg

[redacted]

Benefits of the smart grid

4. **Improving resilience to disruption and being self-healing**

https://i.ytimg.com/vi/_FsRZ-I9_F0/hqdefault.jpg

[redacted]

Benefits of the smart grid

5. Expanding deployment of renewable and distributed energy sources

https://encrypted-tbn3.gstatic.com

[redacted]

Benefits of the smart grid

6. **Automating maintenance and operation**

http://www07.abb.com/images/librariesprovider22/PS/Substations/sunny-beach-1000x600.jpg?sfvrsn=0

[redacted]

Benefits of the smart grid

7. Reducing greenhouse gas emissions

- *Supporting / encouraging the use of electric vehicles*
- *Renewable power generation with low carbon footprint*
- *Reducing the consumption of fossil fuels*

https://cdn.comparethecloud.net/wp-content/uploads/2016/11/wind-farm-hero.jpg

[redacted]

Benefits of the smart grid

8. Enabling transition to plug-in & electric vehicles
   – *EV's can also provide new storage opportunities*

https://upload.wikimedia.org/wikipedia/commons/9/91/Ride_and_Drive_EVs_Plug'n_Drive_Ontario.jpg

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Benefits of the smart grid

9. Increasing consumer choice

- *The use of advanced metering infrastructures*
- *Home automation*
- *Energy smart appliances*
- *Better demand side management*

http://www.texascooppower.com/energy/efficiency/appliances-electronics/how-smart-appliances-interact-with-the-grid

[redacted]

Metering and measurement

- **New digital technologies are employed to enhance power measurement, including:**
  - Two-way communications,
  - a variety of inputs (e.g. *demand response commands*),
  - a variety of outputs (e.g. *real-time consumption data*),
  - the ability to connect and disconnect,

[redacted]

Smart Meters

- A **smart meter** is a new kind of energy meter that can send readings to the utility company via wireless communications.
- This can ensure more accurate energy bills.
- Enhanced information to customers

http://www.which.co.uk/energy/creating-an-energy-saving-home/guides/smart-meters-explained/smart-meter-roll-out/

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Smart Grid Communications

- The smart grid vision can only be accomplished if its foundations are firmly integrated with **robust communication networks**.
- These networks serve as the data exchange backbone to provide **end-to-end bidirectional data communications in the power grid**.
- Examples of technologies being used in smart grid deployments include **cellular data communications, satellite links, fibre optic links, zigbee communications**

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Distributed Generation

Around the world, the conventional power system is facing the following challenges:

- Gradual depletion of fossil fuel resources
- Poor energy efficiency
- Need to reduce environmental pollution.

http://www.iea-coal.org.uk/files/2010ieaccc/website%20images/conventional%20power%20stations/Belchatow4.JPG

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Distributed Generation

- These problems have led to a new trend of **generating power locally**
- These sources can then be **integrated** into the utility distribution network.

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Distributed Generation

- This type of power generation is termed as **distributed generation (DG)** and the energy sources are termed as **distributed energy resources (DERs)**.

http://www.luxresearchinc.com/coverage-areas/distributed-generation

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Renewable power integration - implications

- The integration of a significant share of variable renewables into power grids requires a **substantial transformation of the existing networks**

http://article.sciencepublishinggroup.com/html/10.11648.j.ijefm.s.2015030501.12.html

[redacted]

Renewable power integration - implications

This transformation includes:

a) Ways to allow for a **bi-directional flow of energy**;

b) Establish an efficient **electricity-demand and grid management mechanisms**

c) Improve the **interconnection of grids**, aimed at increasing grid balancing capabilities

d) Introduce **technologies and processes** to ensure grid **stability**

e) Introduce **energy storage capacity** to increase flexibility and security of supply.

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Renewable power integration and smart grid

- The implementation of **smart grid technologies** can act as an **enabler** for these transformations by
  - smart functionality to balance supply and demand
  - increasing flexibility, reliability and efficiency

https://www.metering.com/wp-content/uploads/2015/02/pic-smart-grid.jpg

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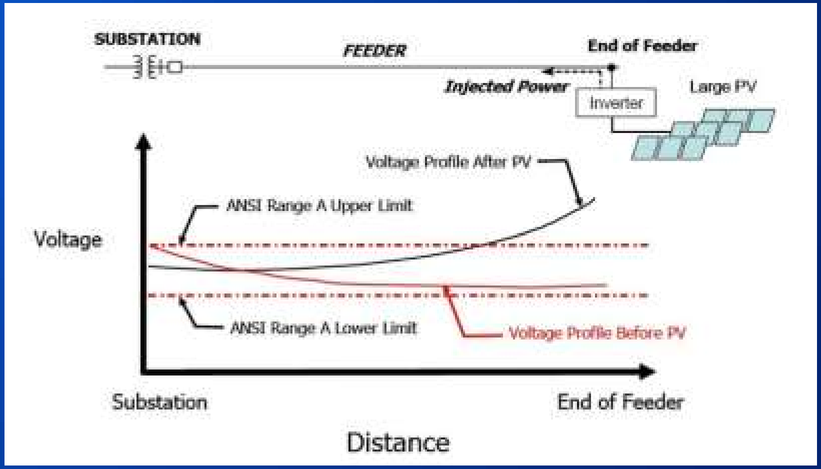
Criteria for renewable power integration

- A major criterion for plant connection is the **impact on the grid voltage** during normal operations (*i.e.* slow voltage variations).



https://germipower.files.wordpress.com/2015/04/figure-11.jpg

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Criteria for renewable power integration

- A further criterion is the **thermal limit** of the grid components (mainly electric lines).
  - These thermal limits are related to the **short circuit levels**, which are increased by the presence of generation in the vicinity of the components.

https://i.ytimg.com/vi/jnnJp-XAZdU/hqdefault.jpg

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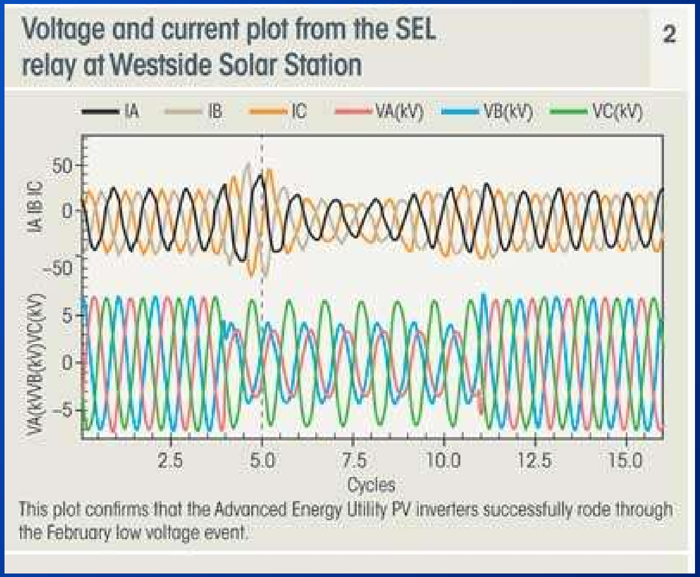
Fault-Ride-Through operation

- The ability of inverter based generation plants to remain connected to the network during network faults — also referred to as **Fault Ride-Through (FRT)** capability — is crucial for large-scale renewables integration into the power grids.



This plot confirms that the Advanced Energy Utility PV inverters successfully rode through the February low voltage event.

http://www.power-eng.com/articles/print/volume-117/issue-5/departments1/what-works/advanced-energy-pv-inverters-ride-through-pg-e-low-voltage-event.html

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Options to facilitate the integration of renewables

Some options to make integration easier:

- Limit renewable generation
- Curtailing
- Using fast responding generators
- Using storage devices
- Demand response

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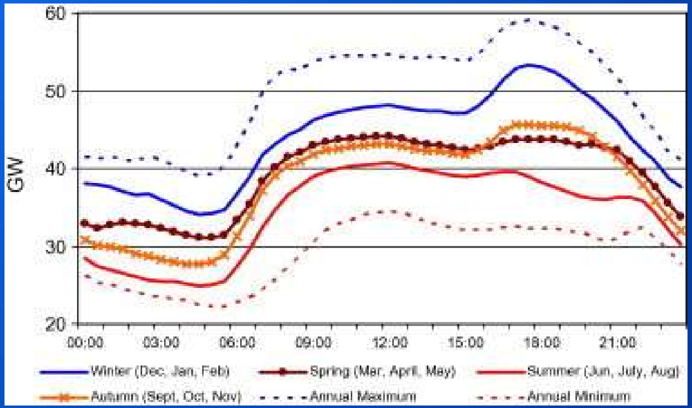
Limited renewable generation

- Consider the seasonal daily demand in the UK:



- Total demand is always more than 20 GW.
- We can assume a base load somewhere below 20 GW.

http://www.theenergycollective.com/robertwilson190/228281/can-solar-keep-uk-s-lights

[redacted]

Limited renewable generation

- If total renewable generation is much less than the base load:
  - Renewable generation can never exceed the demand.
  - We can define net load as

    Net Load = Load – Renewable Generation ≥ 0
- Fluctuation in renewable generation **can be treated just like fluctuations in load demand.**

[redacted]

Curtailing

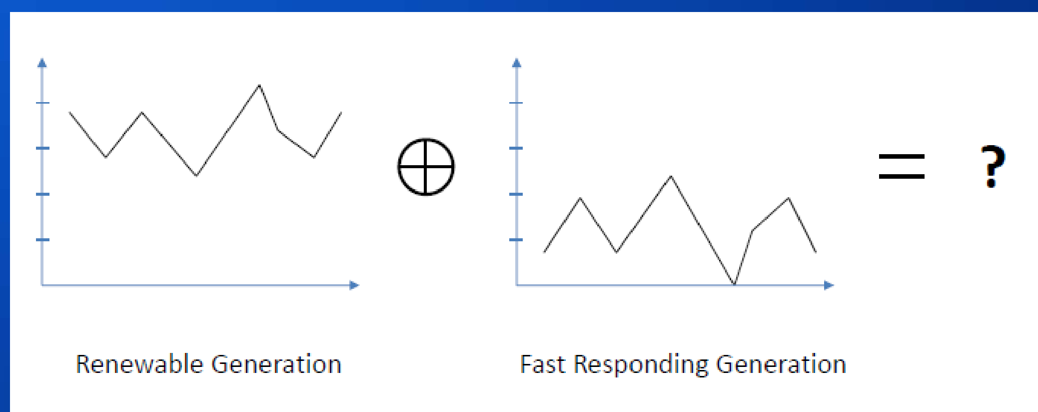
- As we increase the installed capacity of renewable generation:
  - It may happen that generation exceeds load demand
- The key problem:
  - Peak generation may not match peak demand.
- An easy option is to **curtail** excessive generation
  - Shut down (or reduce the power generated by) some wind turbine, solar panels, etc…

https://stopthesethings.com/2017/01/31/sas-wind-power-debacle-aemo-cuts-sas-access-to-victorian-power-to-protect-the-grid/comment-page-1/

[redacted]

Using Fast Responding Generators

- Natural gas plants can quickly change generation level.
- They can compensate fluctuations in renewable power.



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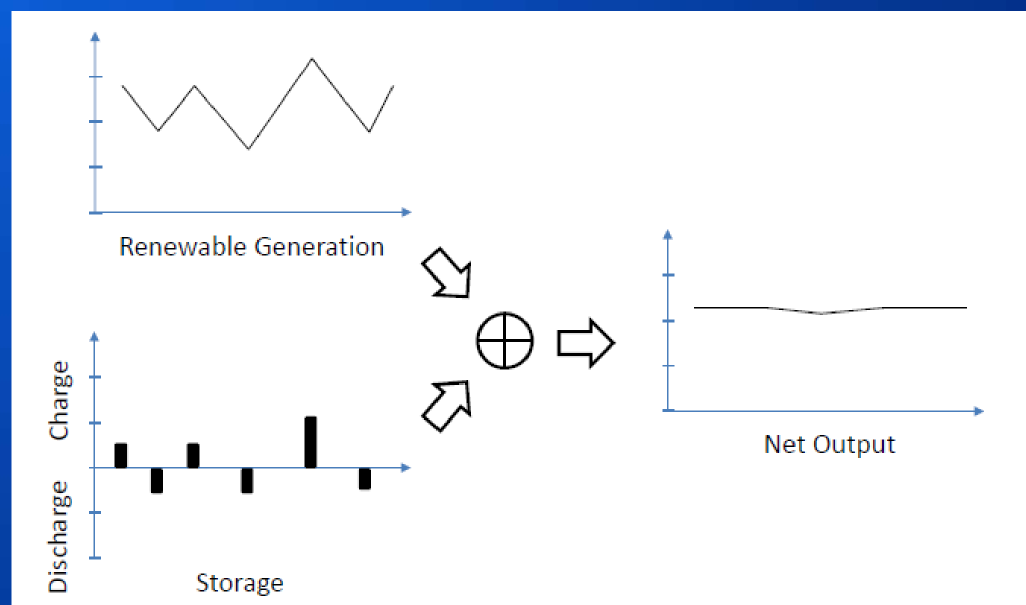
Using energy storage devices

- Charge at higher generation levels. Discharge otherwise.



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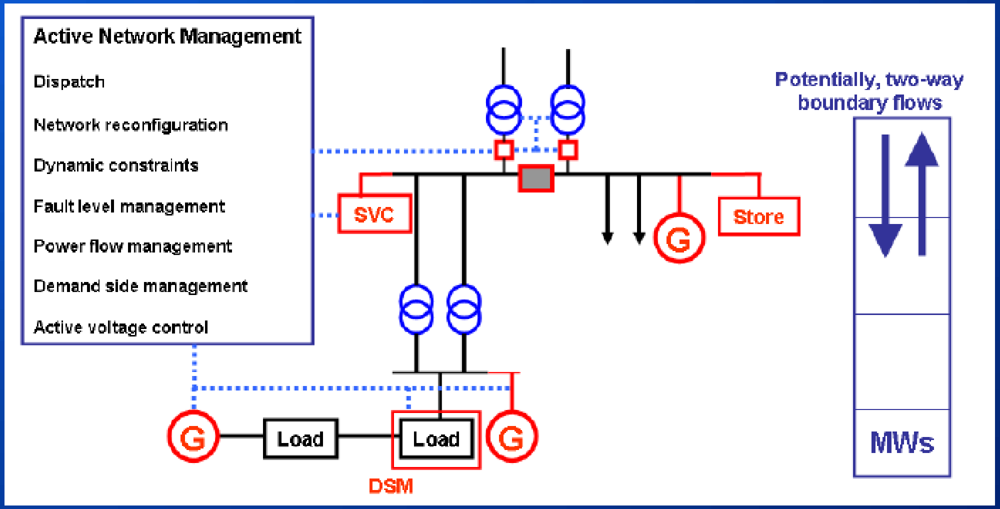
Active Network Management

- Active Network Management (ANM) is a control system that enables the DNO to manage distributed generation, storage and flexible demand in real time.



Source: https://www.ofgem.gov.uk/

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Active Network Management

- ANM brings the following advantages:
  - increases the utilization of network assets
  - Actively avoids breaching operational limits.
  - reduces the need for reinforcement
  - speeds up connections
  - reduces costs.

Components of Active Network Management

The core components required to construct an Active Network Management system are:

1. **Network Monitoring:** The ANM requires near real-time information on the state of the electrical network.

http://www.tendersontime.com/blog-detail/sub-transmission-distribution-network-3410.php

Components of Active Network Management

2. **Enhanced Network Devices (ENDs):** these are active network devices, such as inverters, transformers, voltage regulators or Energy Storage Systems, with machine to machine interfaces capable of sending and receiving operational values. These are the levers ANM pulls to optimise the network.

http://solarprofessional.com/articles/products-equipment/inverters/2009-grid-direct-pv-string-inverter-guide

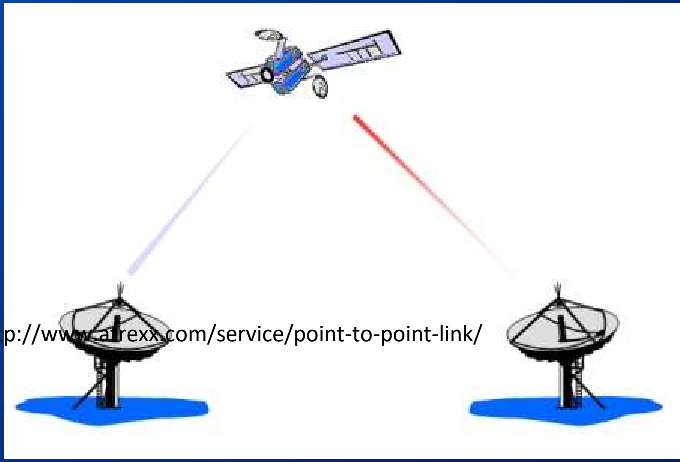
Components of Active Network Management

3. **Remote Distribution Controller**: A local microprocessor device capable of collecting, processing and communicating data.

http://new.abb.com/substation-automation/products/remote-terminal-units/rtu540

Components of Active Network Management

4. **Communications network** – ANM as a dynamic system requires near real-time data. A key requirement then is to have a communications network of suitable bandwidth, agility and reliability.



http://www.airexx.com/service/point-to-point-link/

Components of Active Network Management

5. **Controller** – The element is for processing of the network state over a wide area, and then recommending changes to ENDs to optimise performance. This could be to avoid voltage or thermal constraints.

https://en.wikipedia.org/wiki/Data_center

Components of Active Network Management

6. **Data Warehouse** – A database for storing monitoring and system operation information.

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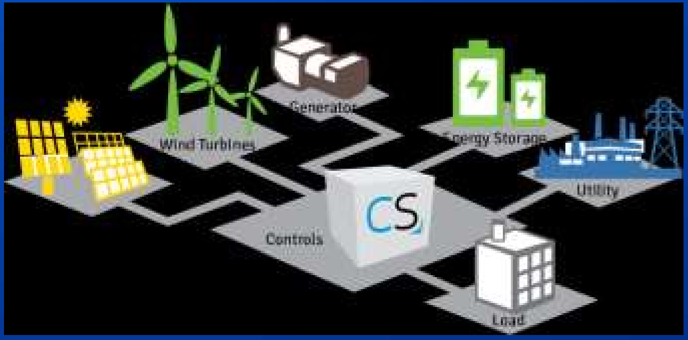
Microgrids

Definition:

A microgrid is a local energy system which incorporates the following three key components: generation, storage and demand, all within a bounded and controlled network. It may or may not be connected to the grid.



http://cleantechnica.com/files/2015/12/blog-microgrid.png

[redacted]

Defining characteristics of microgrids

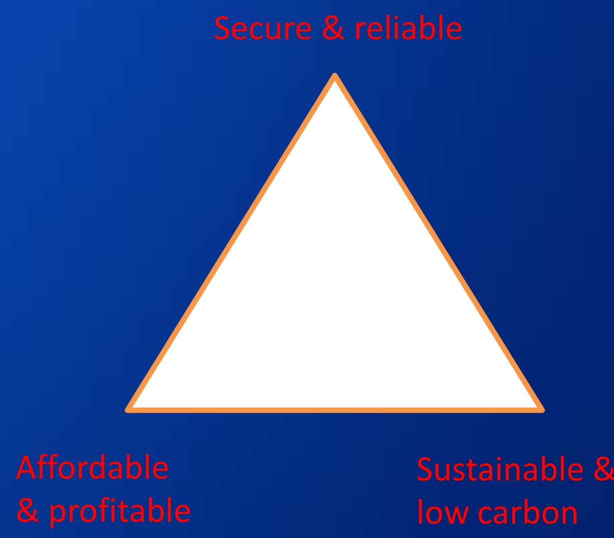
- Grouping of interconnected loads and distributed energy resources
- Can operate in island mode or grid-connected if desired
- Can connect and disconnect from the grid if desired
- Acts as a single controllable entity to the grid

http://www.ewtdirectwind.com/solutions/microgrid-solutions.html

[redacted]

Classification of microgrids

- Remote & off-grid
- Commercial & industrial
- Community and utility (e.g. residential)
- Mission critical (e.g. data centres)
- Institutional & campus (e.g. university)



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Importance of microgrids

- Enable grid modernisation
- Enhance the integration of distributed and renewable energy sources
- Meet end user needs
- Support the main power grid
- Promotes energy efficiency and reduces losses by locating generation near demand

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Thank you