Lectures 1 to 3

Overview of Traditional and Evolving Electricity Grids

Distributed Energy Resources and Smart Grids 4 (DERSG)

Document Comments

This document provides a summary of traditional and evolving electricity grids. Subsequent course documents will provide increased depth and analysis of the listed topics in section 2. Each document will contain recommended literature references and where applicable, useful conclusions obtained from literature which is provided as extra content.

The material is summarised course notes from '*Distributed Energy Resources and Smart Grids 4'*, completed at The University of Edinburgh. Full credit goes to Dr Michael Merlin for delivering an extremely engaging and relevant course. This course is a SCFQ level 10 course (year 4 undergraduate) and accounts for 20 credits.

The course is relevant to students with interests within electrical and mechanical engineering, with a focus on power systems and energy networks. If you have any questions concerning the content within this course series, please contact me. I wish you all the best in your studies!

1: Traditional Electricity Grids

1.1: History and Motivation

The electricity grid has evolved continually from the late 1800's to meet rising customer demands. Some of the first power stations are summarised below:

1. 1879: Dolgeville Dynamo. One of the first hydro power plants which supplied power to local mills using a DC dynamo.
   a. https://edisontechcenter.org/Dolgeville.html
2. 1881: Niagara Falls AC to DC conversion. Small DC dynamo supplying lighting loads. This was later converted to AC.
   a. https://teslaresearch.jimdofree.com/niagara-falls-power-project-1888/

For reference, a DC dynamo is simply an older term to describe a generator that produces DC power. DC power is only sent in one direction and creates DC current using a commutator. Nowadays, a simpler alternator is used for large scale power generation as it is more efficient and reliable.

The first grids were constructed at a similar period, as summarised below:

1. 1882: Edison illuminating company (DC). A DC cogeneration plant by distributing steam.
2. 1886: Great Barrington (AC). Full AC power distribution system at 500V using transformers, Siemens generator and Edison's incandescent lights.
3. 1891: Greater London (AC). Remote AC power station at 11kV supplying central London.

The first transmissions were also constructed at a similar period, as summarised below:

1. 1882: Miescbach, Germany (DC): Large DC transmission at 1.4kV over 57km. This was only for industrial clients.
2. 1884: Lanzo Torinese to Torino (AC). Uses Gaulard and Gibbs transformer to transmit 2kV over 40km on an experimental line.
3. 1889: Lauffen-Frankfurt Germany (AC). Another experimental line which was 175km long at 40Hz. Voltage was initially 8kV but lowered to 55V for a power efficiency of 75%. This line cemented 3-phase systems for future applications.

From these initial developments, it was concluded that DC systems have limited range. AC systems were preferred as they use transformers to boost voltage for low-loss transmission which is then reduced

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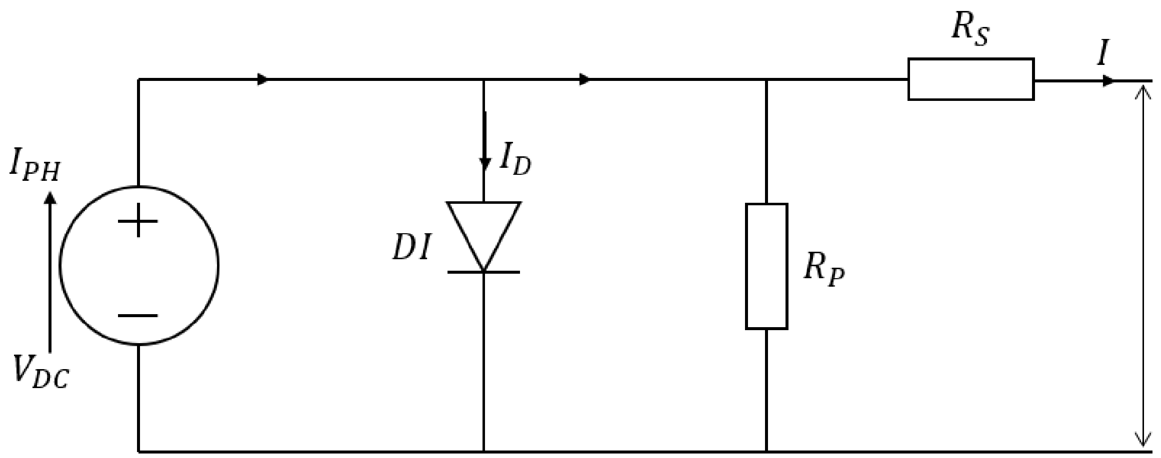
The photon frequency, v, can be found using:

$$v = \frac{c}{\lambda}$$

Where c is the speed of light and λ is the associated wavelength.

3.4: PV Cell

The equivalent circuit of a PV cell is shown.



The lumped resistances hide the actual distributed nature of the resistance. The parallel resistance is present due to current leakage whilst the series resistance is present from material resistance. The diode is a PN junction.

The current, I, can be found using:

$$I = I_{PH} - I_D = I_{PH} - I_O \times \left(e^{\frac{eV}{kT_C}} - 1\right)$$

Where e is an electron charge ($1.6021765 \times 10^{-19}$ C), V is voltage across the cell (V), K is $1.38064852 \times 10^{-23}$ (J/K), T_C is the absolute cell temperature (K), and I_O is the dark saturation current (A).

Manufacturing remains a key cost factor. Current work incldes improving power efficiency as current efficiencies are in the region of 50%.

3.5: PV Panel

A single PV cell will output a voltage close to its PN junction drop, which is around 1V. Subsequently, the PV cells are connected in series or parallel.

Progression of solar topologies goes from solar cell to solar module (multiple cells) to solar array (multiple modules).

Series connection boosts voltage whilst parallel connection boosts current.

Limitations within the configurations are summarised:

- Series: Lowest current generating cell will define the current of the entire branch.
- Parallel: Lowest voltage generating cell will define voltage of the entire branch.
- Limitations result in efficiency reductions or device failure.

Lectures 9 to 10

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$$E = \frac{1}{2}LI^2$$

Using superconducting materials cooled below their critical temperature allows their DC coil resistance to drop close to zero. A superconducting magnetic energy storage system usually includes a superconducting coil, cooling system and power conversion.

Characteristics of high efficiency, low energy density, high power density. Managing the cryogenic cooling temperatures can prove difficult.

2.10: Interconnection to Grid

Power electronics is usually the grid interface as energy storage is often not grid ready. There may be a requirement for active control of the charging and discharging cycles.

Power electronics is also in charge of the state of charge management and all grid related services.