Lecture 12

Electrical energy distribution from power station to home

Part 1: Transmission

This lecture describes transmission

Slide 1: Title slide

Slide2: Bibliography

- B.M. Weedy, B.J. Cory, *Electric Power Systems* (4th Edition)
- Behic R. Gungor, *Power Systems*
- St George's: 621.3191

Slide 3-4: Electrical Power Systems

1. Generation: Making electricity from various sources
    - From large power stations making 11-25kV to small domestic feed-ins such as solar panels on a residential property
2. Transmission
    - Bulk transfer of power from generation to load source.
    - Typically high voltage (HV) of 275 or 400kV depending on distance
    - Higher voltage leads to lower transmission losses
    - National grid: HV Pylons, wires, transformers and substations
3. Distribution
    - Delivering electricity from HV transmission to low voltage (LV) regional distribution systems
    - LV local wires, transforms and substations
4. Supply
    - The process of buying electricity in bulk and selling it to customers
    - You cannot buy directly from the power plant

Slide 5: First central generating system

- In 1882 Thomas Edison unveiled the first central generating station
- His electric supply was 100V DC
- Load was 400 x 83W lamps = 33kW
- There was no legislation or standardisation at the time, which quickly lead to many different voltages, both AC and DC, with many different AC frequencies all transmitting though many, many cables

Slide 6: Voltage and health

- Human resistance depends on cross sectional area (generally larger in males) and the humidity of the skin

- Typically 300Ω (wet) – 100kΩ (dry)
- 100V is considered safe as it is below the "let go" threshold = 10mA
- AC penetrates the skin easily, due to its ability to conduct through the dielectric (capacitance) of the skin.
- Skin is an open circuit to DC, hence conduction at low voltages is along and not through the skin
- AC causes fibrillation by upsetting the hearts natural rhythm
- DC causes more serious burns owing to the larger skin resistance

Slide 7: Wires: voltages and frequencies

- Transmission cables are formed from an Aluminium outer sheath wound around a steel core
- Aluminium is used to conduct the electricity and has ~59% the conductivity of copper but is much cheaper
- Steel is used to strengthen the cable
- Aluminium conductor steel reinforced (ACSR) cable
- Eddy currents (induced currents) counter the flow of current through the core of the wire, limiting conduction to the outer layers, this is known as the skin effect
- The skin effect means the relative resistance is higher for AC transmission, since the effective cross sectional area is lower
- The skin effect is stronger at higher frequencies
- However generators are more efficient at higher frequencies, so there is a trade off which led to either 50 or 60 Hz being selected.

Slide 8: Power loss in transmission

- The total power generated, P = V x I
- For Edison's first generating plant this was 33kW which is 100V at 330A
- The typical resistance of transmission wire is 0.05 Ω/km
- Power loss, P = I^2R
- At 100V: $(330)^2$ x 0.05 = 5.1kW/km lost in transmission
- At 240V: $(137.5)^2$ x 0.05 = 0.88kW/km lost in transmission
- At 1000V: $(33)^2$ x 0.05 = 0.051kW/km lost in transmission
- Clearly transmission is more efficient at higher voltages!

Slide 9: AC vs DC: The war of currents

- Epitomised as Tesla vs Edison, but actually it was a global issue
- In 1882 there was no AC motor and the main loads at the time were either lighting (Edison's patented light bulb) and motors
- In 1883 Tesla invented an induction (AC) motor and equally importantly Gaulard and Gibbs developed the transformer, later perfected by William Stanely (1886)
- The transformer allows for cheap, efficient step up and step down of AC voltage (next slide), and largely ended the war of currents in favour of AC

Slide 10: Transformer

- Transformers can be used to step up a generator's output from 11-25KV to 275/400kV
- Transformers are also used to step down from HV to distribution voltages
- Transformers comprise of a primary and secondary winding around a iron core
- The voltage induced in the secondary (V_s)winding is equal to the turns ratio of the secondary winding (Ns) to the primary winding (N_p) multiplied by the primary voltage (V_p):

$$V_s = V_p \cdot \frac{N_s}{N_p}$$

Slide 11: 3 phase AC

- It is difficult to capture all the induced voltage in a rotating generator in a single coil
- It is easier to increase the number of coils, allowing more power to be generated across the 3 compared to the sum of the power of 1 coil
- For a balanced system, there the currents are equal in all 3 phases, the instantaneous currents travelling in and out of the 3 phases is 0. Hence the 3 phases can be coupled together, reducing the number of wires
- For unbalanced systems, a 4th "neutral" wire is included to cope with the extra voltages and currents. Neutral is tied to ground.

Slide 12: HVDC

- The war of currents was not the end of DC
- AC transmission distance is limited, owing to induction losses in the cables
- AC to DC converters (rectifiers) and DC to AC converters (inverters) are very expensive semiconductor devices
- However the cost of conversion is balanced with the money saved in transmission if the DC link is > ~30km

Slide 13: Transmission and distribution (image)

- Generator
- 400kV HV transmission via pylons
- HV transformer and substation
- 132kV (sub) transmission via (smaller) pylons can go to large industrial users
- HV transformer and substation
- 11kV(start of) distribution can go to small industrial users
- Local transformer and substation
- 400V distribution (giving 230V per phase) to residential users

Slide 14-15: Pylons and Transmission

- Pylons are designed to withstand surges (typically 2.5 – 3x) normal operating voltages
- Pylons consist of a steel frame, ceramic insulators and ACSR cable

- A lightning strike is a common cause of surge, leading to an earth wire at the top of adjoining pylons to capture and ground lightning though the pylon's body
- Other surges and faults commonly involve the substation switching gear malfunctioning

Slide 16-17: Underground cables

- Underground cables are far more complicated than overhead cables
- They are constructed of a conducting core covered in fluid impregnated paper to ensure cooling and insulation
- The fluid is kept at pressure via pumps along the cable length

Slide 18: Overground vs underground

- £500,000 will get you 1km of overhead cable but only 50m of underground cable

Slide 19: Substations and switching gear

- The transmission network is interlinked to accommodate redundant paths to ensure the security of supply (Slide 21)
- A substation consists of:
  - Disconnects: which allow sections of cable to be isolated, but cannot withstand the arcing caused when switching takes place and hence cannot be used in themselves to interrupt power
  - Circuit breakers: used to turn of power, especially designed to cope with the very large short circuit fault current (next slide)

Slide 20: Circuit breakers

- Circuit breakers comprise a copper contact that is pulled apart to interrupt power
- Typically the upper contact is static and the lower contact is drawn away from it
- The entire system is encased in an insulating medium, mineral oil and sulphur hexafluoride are common
- When the contact is broken a very high temperature arc ignites, keeping current flowing
- The insulating medium must quench this arc swiftly to turn of the power quickly and prevent transients and surges

Slide 21: Security of supply

- The national grid comprises interconnected node that support redundant paths
- If a fault occurs on a transmission line, it can be isolated and power re-routed
- The level of security is based on:
  - the economics of the transmission path
  - the cost of power
  - the importance of keeping a particular load centre powered at all times.

Slide 22: National Grid

- 1926 a “grid” was established of the 500 best power stations
- 1948 UK power was finally standardised at 240V / 50Hz AC
    - *Area* boards were set up to oversee distribution and customer service
    - *Generation* boards were set up to oversee electricity generation and HV grid
- 1989-1990 the National Grid was privatised
    - National Gris Company was created to oversee transmission
    - 12 regional electric companies were created to oversee distribution

Slide 23: UK transmission network (image)

- Image depicts the UK transmission network comprising 400kV, 275kV and a 2000MW HVDC link with France
- Note the large degree of interlinking around London (financial and population rich area) highlighting the high priority for security of supply on the captial