Lecture 13

Electrical energy distribution

Part 1: Distribution

This lecture describes distribution and also recaps and clarifies some point from the previous lecture

Slide 1: Title slide

Slide2: Recap (1): AC and DC

1) DC
   a) DC is not defined by a constant voltage, it is defined by a single direction of current flow
   b) DC voltage can alternate between 0 and maximum at high or low frequency and still be considered DC, so long as it does not go negative
   c) For practical applications we try to minimise the AC ripple superimposed on the DC voltage.
2) AC
   a) AC is defined in terms of a current that oscillates between positive and negative with a certain periodicity. Hence the direction reverses once every half cycle.
   b) AC typically has a sinusoidal waveform, but can be triangular or (near) rectangular.
   c) At low frequencies you may imagine electrons drifting forward and backwards along a wire, at high frequencies they more accurately oscillate or "wobble"

Slide 3: AC and DC generation

Simple AC and DC generators are actually very similar. The difference is simply how the power is extracted from the outputs.

1) DC: The dynamo
   a) The dynamo uses a commutator on the outputs. This comprises a split ring.
   b) As the rotor rotates inside the magnetic field, the split ring switches the polarity of the output every half turn.
   c) This keeps the positive output always positive and essentially "rectifies" the output into a modulus of a sinusoid.
2) AC: The generator
   a) An AC generator has two slip rings, which comprise solid rings, and a set of brushes.
   b) The brushes ensure good conduction contact with the rings.
   c) As the rotor, and hence rings, rotate the potential difference form the first ring to the second oscillates from negative to positive and back again.

Slide 4: The dynamo

1) As seen in slide 3, the output from a dynamo varies from 0 to maximum. This means the power "goes off" instantaneously twice per cycle.

2) To reduce the AC ripple, a ring split into 4 quarters can be used instead of two halves.
3) With suitable designing and observation of the timing sequence, one can design a dynamo whose outputs will follow the peaks of the two overlapping rectified sinusoids.
    a) The AC ripple is greatly reduced
    b) But the power extracted is now less than optimal as we are ignoring much of the sinusoids which still putting in the same amount of work to rotate the rotor
4) Similar arguments can be made for a 6 sixths split ring

Slide 5: Recap (2): 3 phase AC

After considering a many split ring dynamo, it is easier to imagine how the first 3 phase AC system was conceived

1) Rather than trying to overlap the outputs to form a single, low ripple DC waveform, 3 phase AC generates 3 discrete AC sinusoids separated in time by 1/3 of a cycle.
2) These phases are termed typically a, b, c or red, yellow, blue, respectively.
3) For AC power, the voltage and current changes direction once per cycle.
4) Current is therefore pulled back and forth through a load, doing work each time.
5) For a balanced 3 phase system, the sum of the instantaneous currents between the 3 phases is zero. This means one side of the 3 phases can be connected together.

Slide 6: 3 phase AC generation

1) Compared to single phase, 3 phase generators are:
    a) Smaller
    b) More efficient
    c) Capture more power per revolution

Slide 7: Phase and line voltages

1) We have thus far considered the phase voltage, that is the voltage on each phase measured between that phase and the central connection (neutral connection).
2) When connecting across two phases (line voltage) one must sum the instantaneous voltages across those phases.
3) It is found that the line voltage is:

$$V_{line} = \sqrt{3}V_{phase}$$

Slide 8: Recap (3): Static and induction

1) Static electricity was first observed by the ancient Greeks (~600BC)
2) Modern electricity relies on electromagnetic induction first observed by Michael Faraday in 1831.
3) Electromagnetic induction relies on a varying magnetic field.

Slide 9-10: Recap (4): Transmission

1) Transformers can be used to step up a generator's output from 11-25KV to 275/400kV
2) Transformers are also used to step down from HV to distribution voltages
3) Transformers comprise of a primary and secondary winding around a iron core
4) 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):

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

5) Overground vs underground
   a) Overground is much cheaper.
   b) Transmission network comprises interconnecting nodes (substations) in order to give redundant paths and security of supply

Slide 11: UK transmission network (image)

1) Image shows 400 and 275kV lines. Note ability to re-route power to any point on the grid due to hubs (substations) and grids of parallel lines (redundant paths).
2) HVDC link to France, links to Ireland and Holland are not shown, but do currently exist.

Slide 12: Electrical Power systems

All electrical system (i.e. Transmission, Distribution and Residential consumption) comprise the same fundamental items. The only difference being that high power, high voltage components are engineered to withstand higher currents and hence have more robust safety and protection.

Systems comprise:

1) Conductance path: Wire
   a) Typically Aluminium or Copper
   b) Cross sectional wire delineated by current carrying requirement
2) Insulation: Air/Ceramic/Plastic/Oil/SF6
   a) Insulation is needed on various parts
      i) Wire is typically air insulated on transmission and distribution networks, this allows the wire to be cooled by air flow. The main requirement is the distance to the nearest adjacent conductor to prevent arcing.
      ii) Household wire is currently insulated with plastic, though in the past it has been rubber, cloth and even paper.
   b) Circuit breakers and transistors on transmission and distribution networks are insulated in oil to facilitate cooling and provide insulation. Circuit breakers are commonly becoming SF6 insulated, due to its greater insulating and arc dissipating properties
3) Switches: circuit breakers, fuses, disconnects
4) Voltage transformation

5) Loads: This can be equipment in your home (kettles, toasters, tvs) or even the actuall sum of resistance of all the wires (on a transmission system)

Slide 13: Characteristics of Electricity

Electricity cannot be stored as actual electricity. It must be changed into chemical (battery) or static charge (capacitor) which is inefficient and low power.

In order to cope with fluctuating demand throughout the day, it is necessary to have electricity ready on demand. This can be achieved by using excess electricity to, say, pump water to a higher reservoir, then when electricity is needed that water can be released through a hydro electric plant for instant power.

There is a growing demand with time for power in new load centres (new industrial / residential sites) and more power in some load centres (expansion of existing sites). Similar there may be a reduction in demand in some load centres (derelict / abandoned industrial sites).

The path a transmission network takes is strictly controlled by “wayleaves” (rights of way) just like road and rail. Actual transmission line locations and routings are a combination of forward planning and natural (organic) evolution of the existing system.

Electricity is typically generated far from load centres, often a result of the location of the fuel. Here fuel can be coal/oil/gas/nuclear which is either cumbersome or expensive or dangerous to transport near load centres, or it can be “fuel” in a looser sense like a hydro-electric plant on a river, where the river is an ideal generation point but is far from the load centre.

Slide 14: Distribution Network Operators (image)

An image listing the distribution network operators around the UK by area

Slide 15: Distribution

Distribution utilises lower voltages than transmission. The sub-transmission voltage of 132kV is used in the UK as an interim between the higher voltage (400 / 275kV) transmission network and the actual distribution network. The voltage is successively stepped down as it reaches the load centre. Typically 66kV to 33kV to 11kV to 6.6kV to 400V (3 phase) which is 230V single phase. The step down need not necessarily involve every voltage listed, but always reaches 400V for residential use.

Slide 16-17: Supply: Where to buy?

Customers do not buy their electricity directly from generators. An electricity supplier buys “bulk” electricity from a generator and then either sells that onto the customer or an additional supplier. Supplier to supplier sales are common for “green” energy since a green generator produces less power than a typical fossil fuel plant, and it is more feasible to sell all the power to one supplier for further distribution.

In order to become a supplier one must have:

1. A licence from the Office of Gas and Electricity Markets (OFGEM)

2. Codes of practice from Association of Energy Suppliers (AES)

The codes of practice outline you customer support statement, including details of how you will receive payments, how you will ensure security of supply, what you will do in a brown out, etc

To entice customers, suppliers give special discounts and offers such as dual fuel discounts. Or even guaranteeing a specific fraction of green energy and a pledged carbon footprint.

The generator-supplier relationship can be privately or government regulated. Large scale power production can have a monopoly on the local energy generator and is heavily regulated to ensure fair pricing.

Smaller scale (green) generators typically have a power purchasing agreement with one or more suppliers to fix the cost and term of the electricity to be purchased. This includes a clause regarding what to do in the event the “fuel” or source of energy is unavailable. Such as no wind or sun that day!

Slide 18: Three phase residential distribution

The final transformer that drops the voltage to 400V 3 phase (230V single phase) is typically located on a street in suburban area or in a high rise building (usually the basement) in dense city centres. The power is transmitted as 3 phase on 3 wires. The transformer substation provides a neutral wire at the join of the 3 phase wiring on the output side of the transformer. Each house then receives single phase electricity taken from the neutral wire to either Red, Yellow, Blue. It is not necessary to know which phase you actually have, since you only utilise that one phase within your property.

Attempting to connecting two phases into a single loop, i.e. joining yellow to blue, results in a short circuit across the LINE voltage (415V) resulting in enormous currents.