Lecture 18 notes

Electricity in the home

Slide 1: Title

Slide 2: Bibliography

- http://www.tlc-direct.co.uk/Book/1.1.htm

Slide 3: 3 phase residential distributions

- The final distribution transformer steps down the 3 phase line voltage to ~400V.
- The single phase voltage is therefore ${}^{400}/_{\sqrt{3}}$ = 230V
- Neutral is provided and defined at the transformer at the central point of the "star" connection. The central point is also linked directly to ground (i.e. the earth).
- Each residential property receives neutral and a one of the 3 phases. The actual phase is incidental, however care is taken to distribute the phases evenly on each transformer. This is in order to ensure some quasi-balance in the loading.
- The load will never truly be balanced, since each house will have a different instantaneous demand. Hence the neutral line will always hold a non-zero current.

Slide 4: Single Phase: Live, Neutral and Earth

- Single phase comprises 3 wires
  - Live: 230Vac
  - Neutral (slide 9)
  - Earth: A low impedance path to earth (slides 5-8)

Single phase colours:

Wire	**Old colours**	**New colours**
Live (L)	Red	Brown
Neutral (N)	Black	Blue
Earth (E)	Green	Green/Yellow stripe

Slide 5-8: Earth wire

- The earth wire is a physical contact to earth defined either:
  - Locally at the property with an earth rod
  - At the final distribution transformer
- Types of earth:
  - Older properties (where mains consists of an overhead live and neutral line) require earth to be defined locally via an earth rod driven deep (>1m) into the ground
  - Newer properties, where mains enters via an underground shielded cable, typically use the outer metal sheathing as earth. This is pinned to a good earth at the transformer.
- Uses of earth

    - Safety: Prevent build up of static
    - Safety: Path to ground in case of insulation failure
    - Reference: The earth is used as a potential reference point. All voltages are defined as a potential difference from earth.
    - Fault current: The earth is an infinite sink source, hence it is be able to sink any fault current that could potentially exist on the line. A higher fault current ensures the protective devices (fuses or circuit breakers) will trip.
    - Low impedance: The earth is low impedance (resistance), typically, hence there a very small low voltage drop on the line and even in fault state there should be insufficient voltage/current to cause serious injury.
- A local earth must meet a certain standard of low impedance. A common way of testing an earth's impendence is an "earth loop tester" just after the mains enters the property.
    - A fault condition is established (isolated from the rest of the property) and the voltage across and the current through a resister are measured.
    - The voltage drop across a 7kΩ resistor is used to determine the actual resistance of the earth. The standard was a earth resistance of 1.6kΩ, giving a voltage drop of ~50V to earth. More recently the requirement has become more stringent and it typically ~100Ω, giving a voltage drop of ~3V to earth.
- Ultimately an electric circuit can either be floating or grounded
- Grounded: Completely define all points on a circuit
    - Expensive infrastructure
    - "Guaranteed" safety
- Floating: Define nothing respect to anything!
    - "Complete" isolation from earth, though leaking through insulation means it is never perfectly isolated!
    - Cheaper

Slide 9: Neutral wire

- The neutral wire is defined at the final distribution transformer.
- The (sub-)transmission network has no neutral.
- The neutral connects the centre of the transformer's output phases to ground (earth)
- All connections from neutral to residential properties are via a bus bar (essentially a high conducting copper terminal that can be considered to be at the same potential at any given position.
- The earth bus bar is somewhat similar to the neutral bus bar, save that it is NOT connected to the transformer coils! As such it is entirely isolated from neutral and live.

Slide 10: Residential wiring

- The actual phase (red/blue/yellow) is not important from a user point of view.
- The cable entering a residential property can take several forms.
    - Old over head: Red/Black only. Earth defined at the property

  - New over head: Brown/Blue. Earth defined at the property
  - New underground: Brown/Blue/Sheath. Where the sheath is earth (green/yellow stripe)

Slide 11: Electricity in the home

- Once the wiring enters a property they pass into a distribution (consumer) unit.
- The live, however, first passes through:
  - A main fuse
  - A isolation switch
  - An earth tester (if the earth is not supplied from the transformer)
- The consumer unit provides individual circuits each with their own current protection rating (slides 17-18)
- The circuits are typically:
  - Lighting (6A)
  - Radial (20A, 32A with thicker cable)
  - Ring (32A)
  - Cooker (32-40A)
  - Shower (40A)

Slide 12-13: Fuses

- The fuse is a sacrificial device for over current detection
- The first “fuse” was conceived by Breguet in 1847 in order to protect delicate telegraphy equiptment from lightning strikes to the cables
- The modern fuse was patented by Edison in 1890 after further development
- Fuse construction depends on the operating current, generically:
  - Wire: small cross section
  - Wire material: Zn, Cu, Al, Ag
  - Housing: Glass, ceramic, plastic, fibreglass
  - Inner medium: Air, sand (HV)
  - Variations: solder fuse, spring fuse
- Fuses are characterised via:
  - Rated current: A maximum current that the fuse can continuously conduct without interrupting the circuit.
  - Rated voltage: Voltage rating of the fuse must be greater than or equal to what would become the open circuit voltage. A fuse rated at 110V, would not reliably interrupt 230V.
  - Speed: The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made. The operating time is not a fixed interval, but decreases as the current increases. Fuses have different characteristics of operating time compared to current, characterized as *fast-blow*, *slow-blow*, or *time-delay*, according to time required to respond to an overcurrent condition
  - I^2t value: The amount of energy spent by the fuse element to clear the electrical fault.

- Voltage drop: A voltage drop across the fuse is usually provided by its manufacturer. Resistance may change when a fuse becomes hot due to energy dissipation while conducting higher currents. This resulting voltage drop should be taken into account, particularly when using a fuse in low-voltage applications.
- Break capacity: The breaking capacity is the maximum current that can safely be interrupted by the fuse.

Slide 14-15: Circuit breaker

Circuit breakers, like fuses, come in a variety of shapes and sizes. Though generically, a circuit breaker consist of a means to:

- detect a defined fault condition
- Cut off (break) current flow
- Suppress arcs

A mechanical (sometimes miniature) circuit breaker, MCB, is currently employed in favour of fuses in a consumer unit.

An MCB comprises:

- Actuator lever and mechanism to reset solenoid in the MCB
- Contacts that open to interrupt current flow
- Terminals for external connection to the live wire
- Bimetallic strip to open in the event of sustained small over current owing to heating
- Calibration screw for the manufacturer to adjust the trip condition
- Solenoid to detect and actuate the trip
- Arc divider / extinguisher to ensure arcs are suppressed and current is swiftly terminated

Slide 16: Residual current devices

Here we consider a residual current circuit detector (RCCD), another kind of circuit breaker

The RCCD breaker relies on the L and N wires passing through a iron core. Each wire then induces an equal and opposite magnetic field. The two field cancel out and no overall voltage is induced in the magnetically coupled trip relay.

An imbalance in either L or N wire (caused for example by contact with a human being) causes an imbalance in the magnetic fields, which induces a voltage in the trip relay, opening the circuit and stopping the (human being) from sustained electrocution.

Slide 17: Consumer unit

A consumer unit comprises:

- a number of MCBs with a rating appropriate for the current demand
- one (more recently two) RCCDs on series with the N wire.
- Bus bars for Earth and Neutral

- The Neutral has a bus bar for each RCCD and another non-RCCD-protected busbar. Essentially the bus bar is split, allowing the upper floor circuits not to be affected by a trip on the ground floor circuits
- The separation of circuits via the split N bus bars is a combination of common sense and personal preference.

Slide 18: Wires and loops

The wires comprising each circuit have various cross sectional areas (CSAs) that define their maximum current carrying capacity/rating. The actual rating depends on the insulation and the medium through which the wire is routed: air, wall (without/without cavity), underground, etc.

Diversity is used to predict the normal operational demand of a circuit as a fraction of the full power. For example a cooker comprising 4 x 1.5kW hobs, 1 x 2kW grill, 1 x 2kW top oven and 1 x 4kW main oven has a total (maximum) power of 14kW however all features will not run under sustained operation, simultaneously at full power.

Each circuit/device has its own diversity equation. The diversity of a ring circuit is defined as

$$100\%X + 40\%(Y+Z)$$

where:

- **X** is the full load current of the largest appliance or circuit
- **Y** is the full load current of the second largest appliance or circuit
- **Z** is the full load current of the remaining appliances or circuits

Slide 19: Lighting

A lighting circuit comprises a radial L, N and E wire running from room to room through a distribution point known as a “ceiling rose”

In the ceiling rose:

- the L is passed into a L-terminal
- a spur is taken down into a switch
- the other side of the switch passes into a switch-terminal
- a second wire passes from the switch terminal to one side of a light fitting (bulb)
- the circuit is competed by a final wire passing into the N-terminal
- closing the switch then allows current to flow from L to N, operating the bulb

Slide 20: Radial vs Ring circuits

The sockets in a residential property are connecting by either a radial or ring circuit. The choice of which is often an economical one.

Radial circuits:

- are suited to long runs, where returning a wire to the consumer unit (to create a ring) would effectively double the length of the circuit.
- Are rated at 20A (MCB) for a 2.5mm^2 CSA cable
- Can be extended by simply adding another socket to the "end of the line"

Ring circuits:

- offer higher current capacity through a wire of lower CSA, since each socket on the circuit is essentially fed from 2 wires in parallel (doubling the effective CSA.
- Are rated at 32A (MCB) for a 2.5mm^2 CSA cable
- Can be extended by either:
  - Adding a spur to an existing socket (to a maximum 1 spur per socket to keep the same 32A rating)
  - Opening up the circuit and re-routing the wires both in and out of the removed socket into the new socket. Cumbersome and in some instances impossible.