



University
of Exeter

Centre for Smart Grid

L3 HV and LV Distribution Networks

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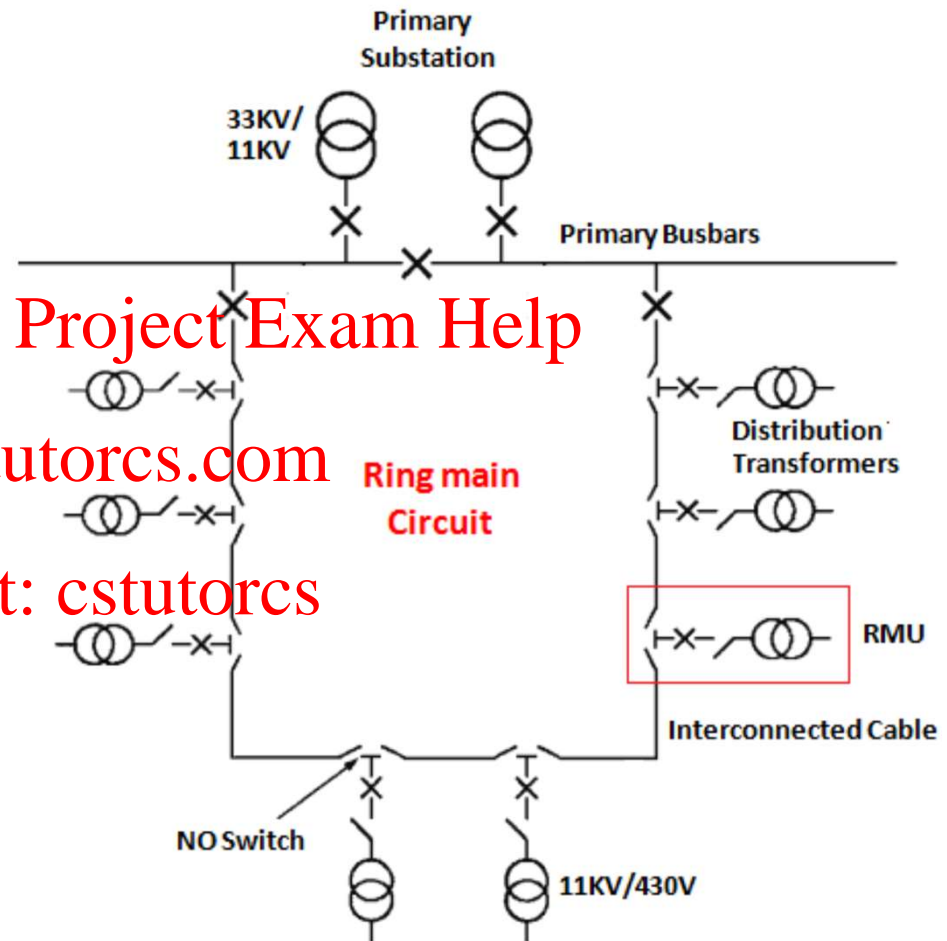
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Prof Peter Crossley



HV open ring, supplying LV radial feeders

- Normal method of 11kV or 6.6kV distribution is an open ring circuit feeding from the primary substation to normal open points.
- Load on any teed section or group of teed substations between switching points is usually restricted to 1MVA.



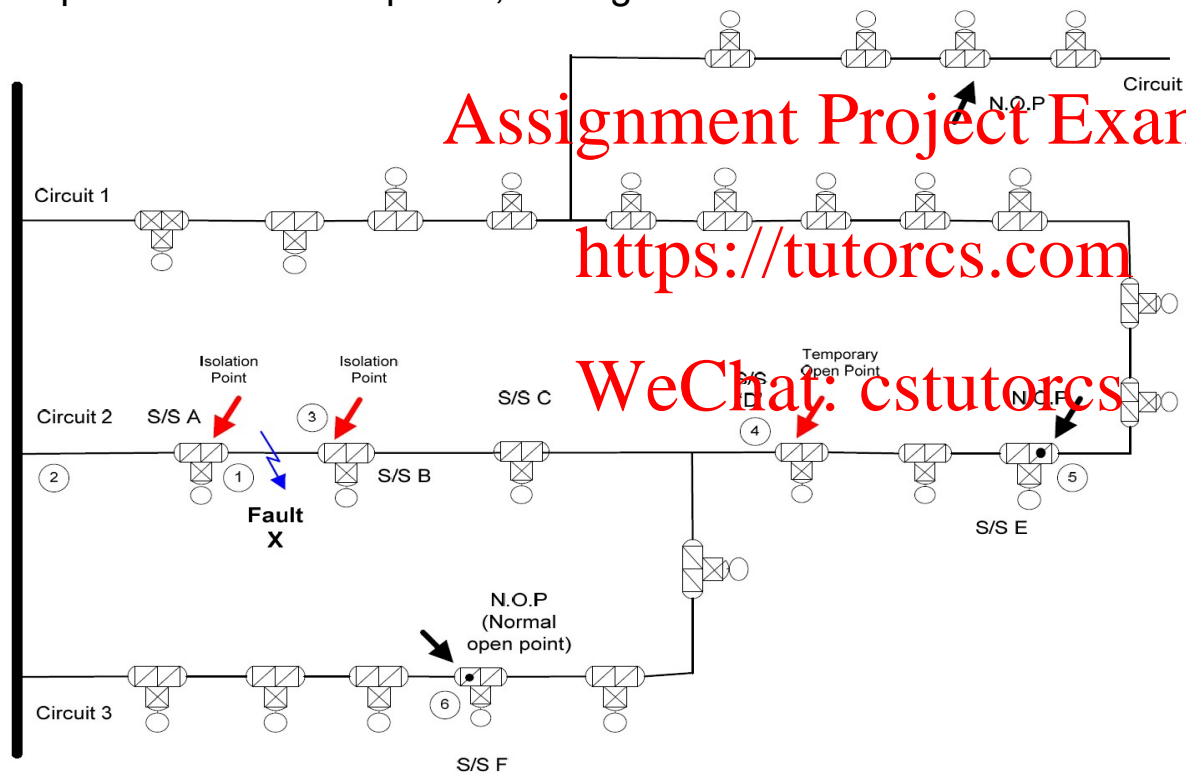
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Supply restoration after fault.

- For 11kV fault outage, alternative supplies are normally restored to healthy sections of network by single load transfer plus restoration from source circuit breaker (4 switching operations).
- On established networks with small section cables this may not be possible, hence 6 switching operations are acceptable; see figure below.



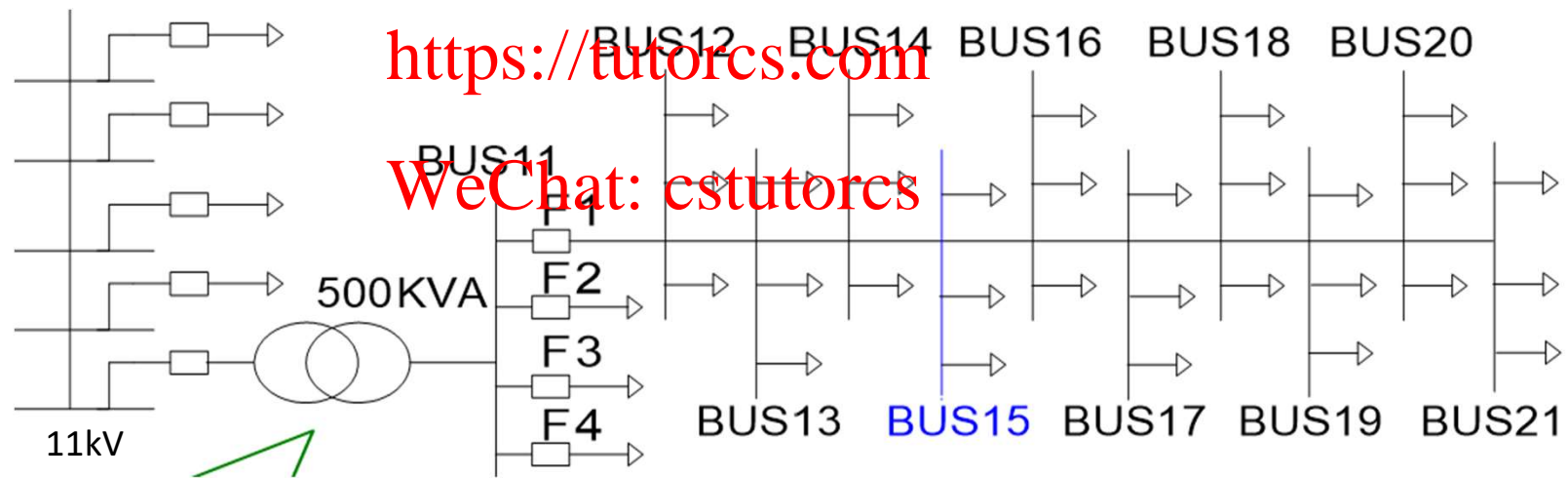
For a fault at 'X'

Following trip of feeder circuit breaker and confirmation that the fault is between substations A & B it should only be necessary to carry out a maximum of six switching operations to restore customer supplies

1. At substation A -.Open substation B Gas switch
 2. At primary substation - Close circuit 2 circuit breaker.
 3. At substation B - Open S/S A Gas Switch
 4. At substation D - Open S/S C and Tee Gas Switch
 5. At substation E - Close N. O. P.
 6. At substation F - Close N. O. P.
- } Additional Load Transfer

LV NETWORK DESIGN

- LV networks are normally designed as radial, fed from the secondary substation via fuses to open points in network link boxes.
 - An exception is central London, due to high demand in the area of the West End to the City.
 - In this area the LV network is electrically connected together via fuses across HV feeders to support the high LV load density by providing multiple infeeds and to maintain supply to LV loads in the event of an HV fault.
- Supplies to loads of less than 800kVA will generally be made at LV.



11kV:430V transformer
(200kVA – 800kVA)

LV Network = 4 feeders protected by fuses
Example: Feeder F1 is 300m and it supplies, via 10 load connection points (LCP), 96 customers, evenly distributed across the phases

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Calculation of domestic LV Demand

- Calculation of demand is dependant upon number of connections and designer's estimate of annual unit consumption of each connection. The table below indicates the classifications of properties and typical unit consumptions used by UK Power Networks.

ADMDs (kW)

Type	Day	Night
1/2 Bed Gas C/h	1.2	0.3
3 Bed Gas C/h	1.5	0.3
4 Bed Gas C/h	1.8	0.5
5+ Bed Gas C/h	2.4	0.5
1/2 Bed Other C/h	1.5	2
3 Bed Other C/h	1.9	2.5
4 Bed Other C/h	2.1	3
5+ Bed Other C/h	3.1	3.5
E7 1 Heater / W/h	2.2	5.13
E7 2 Heater / W/h	2.5	7.56
E7 3 Heater / W/h	2.8	9.99
E7 4 Heater / W/h	3.4	12.42
15kW Boiler	4.5	16.2
19kW Boiler	5.7	19.8

- After diversity maximum demand (ADMD) is used in the design of distribution networks and assumes demand is aggregated over large number of customers.
- ADMD accounts for the coincident peak load a network is likely to experience over its lifetime and as such is an over-estimation of typical demand.
 - If you live in a 3 bed Gas c/h house your energy use (kWh) per year based on ADMD and 8 hour nights is almost 10MWh = £1700 for kWh + standing charges (£70). In reality, kWh part of your electricity bill is probably about £400 - £500, hence annual kWh demand is 2.2 – 2.7MWh, which translates to average kW use of 250W – 300W.
 - Problem is the time we all want to use electricity.
- Would time-of-day pricing change when you use your kWh's?
 - Is 5p – 50p per kWh, enough to shift the demand peaks?

- What happens to LV networks, when we all stop using Methane Gas for Central Heating and switch to electricity powered heat pumps.
- Similarly, what happens when domestic consumers switch to EVs and decide to charge at home.

Calculation of LV Demand:



Calculation of ADMD and site maximum demand for a new housing development:

The site maximum demand shall be calculated using the following formula:

$$\text{Site Maximum Demand} = (\text{ADMD}_w \times N) + 8 \text{ kW}$$

Where:

- ADMD_w is the weighted average ADMD per household within the site.
- N is the total number of houses.

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To arrive at the weighted average of the After Diversity Maximum Demand the following rule applies:

$$\text{ADMD}_w = \frac{(N_a \times \text{ADMD}_a) + (N_b \times \text{ADMD}_b) + \dots + (N_z \times \text{ADMD}_z)}{N_a + N_b + \dots + N_z}$$

For example, if it is planned to connect 20 houses with an ADMD of 5 kW and 60 houses with an ADMD of 3 kW, the weighted average ADMD would be 3.5 kW as below:

$$\text{ADMD}_w = \frac{(20 \times 5) + (60 \times 3)}{20 + 60} = \frac{280}{80} = 3.5 \text{ kW}$$

Therefore: $\text{Site Maximum Demand} = (3.5 \times 80) + 8 = 288 \text{ kW}$

The specific ADMD figures for each household will vary depending on the size of the house, the type of heating system installed and the presence of low carbon technologies. Given the ongoing and forecast uptake of low carbon technologies, ADMD values must reflect the electrification of heat and transport. This ensures adequate supply capacity is provided at the time of construction and avoids future network issues arising from thermal or voltage constraints.

LV Demand: challenges on networks for a low-carbon future

Baseline ADMD values:

Type of Heating	Type of House	Estimated Annual Consumption (kWh)	ADMD (kW)
Gas Hot Water and Central Heating and/or 3kW Immersion Heater	≥ 5 Bedroom property	5000	2.0
	4 Bedroom property, or 3 Bedroom detached property	4250	1.5
	1 or 2 Bedroom property, or 3 Bedroom non-detached property	3500	1.0

ADMD modifier for electrically heated homes:

Type of Heating Scheme	H (kW)	ADMD (kW)
Water and Space Heating (Property EPC* Rating A-C)	Total heating load including water heating, storage and panel heaters	+ 0.5H
Water and Space Heating (Property EPC* Rating D-G)	Total heating load including water heating, storage and panel heaters	+ 0.6H
Electric Central Heating Boilers	Total value of installed storage space heating only	+ H
Heat Pump (air/ground source)	Total installed Heat Pump capacity	+ H

EPC* = Energy Performance Certificate; typically A-C for a new build property. Where no data is provided assume D-G.

ADMD modifier for EVSE/EV charging:

LCT Status	EVSE installation	EVSE Rating (kW)	ADMD (kW)
EVSE or EV charge point to be installed for domestic EV charging	Slow Charging	3.68kW (16A)	+ 1.5
	Fast Charging	7.36 (32A)	+ 2.5
* EVSE not installed but off-street parking is available	Not installed at time of construction	-	+ 1.5

*Only applied if no other charge point equipment is specified.

Tables illustrate the challenges networks will face in the future.



Calculation of LV Demand:



Examples

- A. A 3 bedroom detached property with off-street parking, 4.8 kW of installed panel heaters, an EPC rating of A and available will have a property specific ADMD of 5.5 kW:

$$1.5 + 0.5(4.8) + 1.5 = 5.4kW = 5.5 kW$$

- B. A 5 bedroom property, 7.2kW of installed panel heaters, an EPC rating of A, and an installed Fast Charging EVSE will have a property specific ADMD of 9.0 kW:

$$2.0 + 0.5(7.2) + 2.5 = 8.6 kW = 9 kW$$

- C. The weighted $ADMD_w$, for the above two properties is found as follows:

$$\frac{(1 \times 5.5) + (1 \times 7.5)}{2} = 6.5kW$$

- D. The *Site Maximum Demand*, for the above two properties is found as follows:

$$(6.5 kW \times 2) + 8 = 21 kW$$

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Impact of EVs & Heat Pumps:

Heating

PUHZ-(H)W50-140VHA(2)/YHA2(-BS)
Ecodan Monobloc Air Source Heat Pumps



Mitsubishi range of Ecodan monobloc air source heat pumps includes 5, 8.5, 11.2 and 14kW sizes, designed to cascade up to 6-units.

- Peter lives on a road with 86 houses, each connected to overhead 3Φ LV line supplied by 300kVA transformer.
- All houses large & detached, most built in 1950's and later extended.
- 2021 guess: all heated by gas & small number with EVs, PV & solar thermal panels or Heat Pumps.

- Guess "mean" ADMD for each home today is 2kW.
- Hence 86 homes = 172kW (OK for 300kVA transformer)
- If we assume everyone switches to fast charging EVs and large Heat Pumps (14kW capacity)
- ADMD for each house $\approx 2.0 + 4.8 + 2.5 = 9.3\text{kW}$
- Hence 86 homes $\approx 800\text{kW}$ (300kVA transformer & line overheats).

- **What are the solutions, other than new transformer & higher rated line ?**

OUTDOOR UNIT		PUHZ-W50VHA2(-BS)	PUHZ-W85VHA2(-BS)	PUHZ-W112VHA(-BS)	PUHZ-HW140VHA2(-BS)
HEATING ² (A-3/W35)	Capacity (kW)	4.8	8.3	11.0	14.0
	Power Input (kW)	1.63	2.96	3.65	4.81
	COP	2.95	2.80	3.01	2.91
ELECTRICAL DATA	Electrical Supply	220-240v, 50Hz	220-240v, 50Hz	220-240v, 50Hz	220-240v, 50Hz
	Phase	Single	Single	Single	Single
	Nominal Running Current [MAX] (A)	5.4 [13]	10.3 [23]	11.2 [29.5]	14.9 [35]
	Fuse Rating - MCB Sizes (A) ⁶	16	25	32	40

Voltage Regulation:

- At LV, the supply voltage must remain within the declared voltage range of 230 volts +10% and – 6 % during normal running and outage conditions.
- Maximum Voltage on LV distribution feeders shall **not** exceed 253V;
- Minimum Voltage at the distribution system Exit Point shall **not** be less than 216V;
- Maximum voltage regulation from LV busbars of HV/LV substation to the end of each main feeder shall not exceed 5%. Assuming no generation on feeder:
 - if LV at substation is 253V, then minimum voltage at end of longest “heavily loaded” feeder > 240V.
 - If LV at substation is 227V, then minimum voltage at end of longest “heavily loaded” feeder > 216V.
- Maximum voltage regulation in any service to customer from main feeder shall not exceed 2%.

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Substations:

- Substations must be sited as closely as practical to the major load centre(s) and must allow 24 hour unimpeded access.
- Designs incorporating substations in sub-optimal locations cause increased system losses and will NOT be approved.
- Substations in areas below ground will not generally be accepted.
- Choice of enclosure will be influenced by an assessment of the likely risks to arise from interference, vandalism or unauthorised access.
- Other security measures may also be required.

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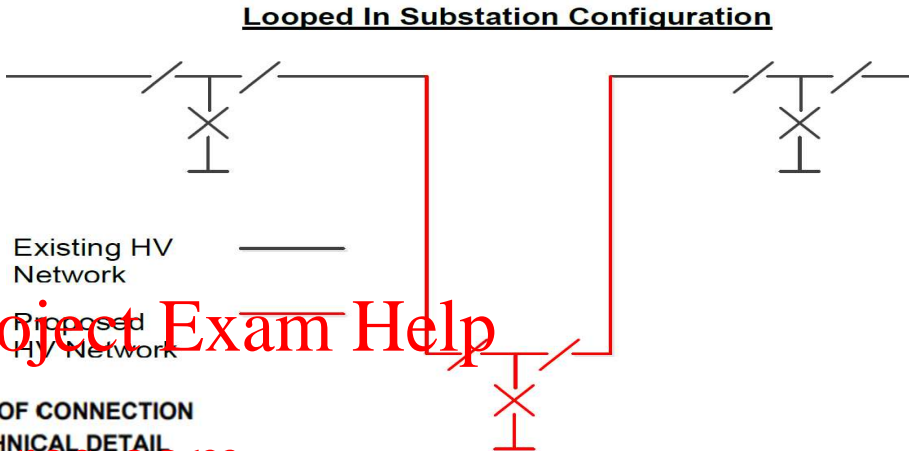
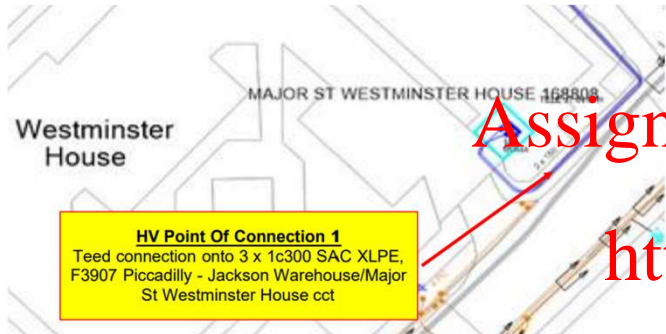
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Housing Development, underground supplies and HV/LV substations:

New substation to be looped in between HV Point of connections 1 & 2

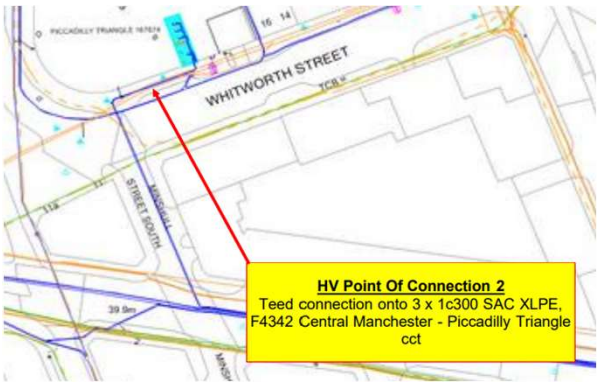


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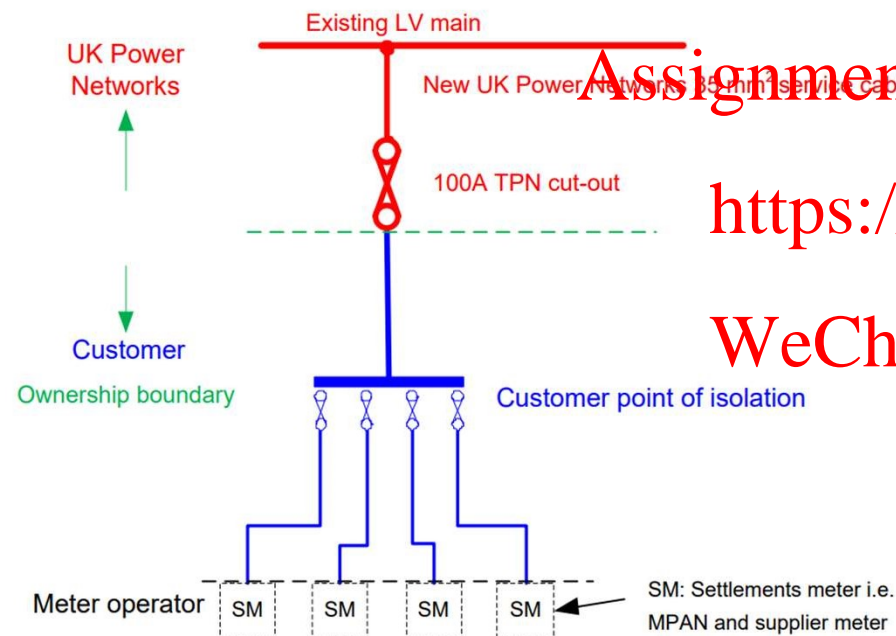
Cable Size @ P.O.C :	see drawing
Voltage :	6600 volts
Minimum Cable Size :	
Loop or Teed (HV only)	Looped
Feeder Name / No :	Jackson Warehouse/Major St
Transformer Size :	kVA
Fuse Size :	Amps
Earth Loop Impedance :	ohms
% Voltage Drop	
1) Including site load	%
2) excluding site Load	%



EDS 08-2100 LV CUSTOMER SUPPLIES

- Guidance on provision of LV supplies between 100A & 2165A (23kVA to 1.5MVA).
 - Supplies of > 1.5MVA to a single customer shall be provided at HV.

A 100A three-phase and neutral (TPN) supply shall be provided via 35mm² three-phase service cable terminated into a three-phase 100A cut-out. Maximum ratings of fuses = 100A.



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Service length limited to 43m to ensure maximum voltage drop of 6% at customer supply terminals.

Comment: if your home is located at the remote end of longest main cable, the minimum "acceptable" voltage is 216V.

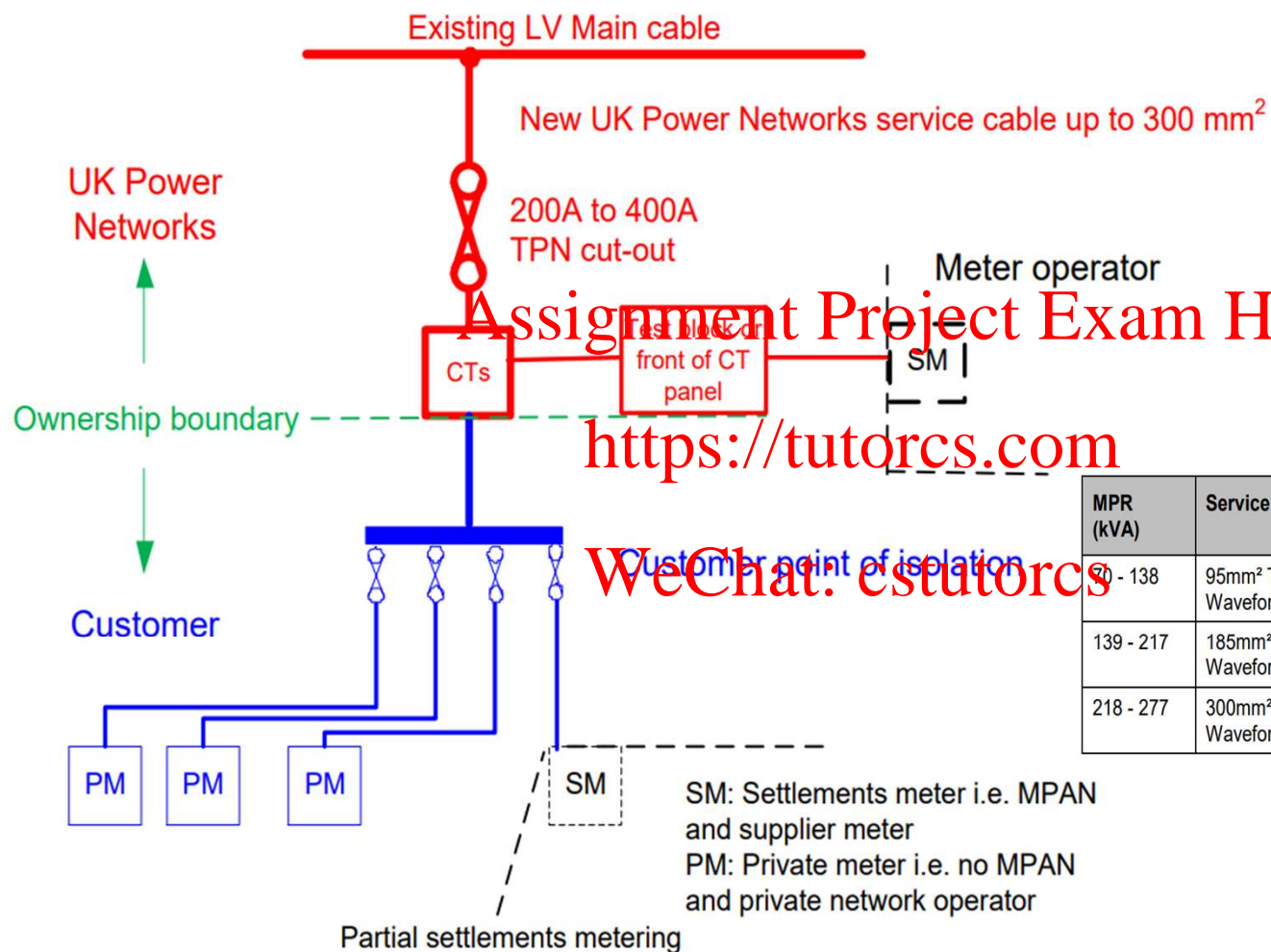
Slide 11 quoted 5% drop from start to end main cable. This slide, quotes 6% for customer tee.

Note: minimum LV voltage at HV:LV transformer is 241V.

Hence, if minimum LV transformer voltage is 241V, and maximum 5% drop for main feeder and 6% for customer tee, then voltage at most remote customer is 215V. Is this acceptable??

Assume highest acceptable LV transformer voltage 254V (assumes no load on transformer)

EDS 08-2100 LV CUSTOMER SUPPLIES (200A – 400A 3Φ supplies)



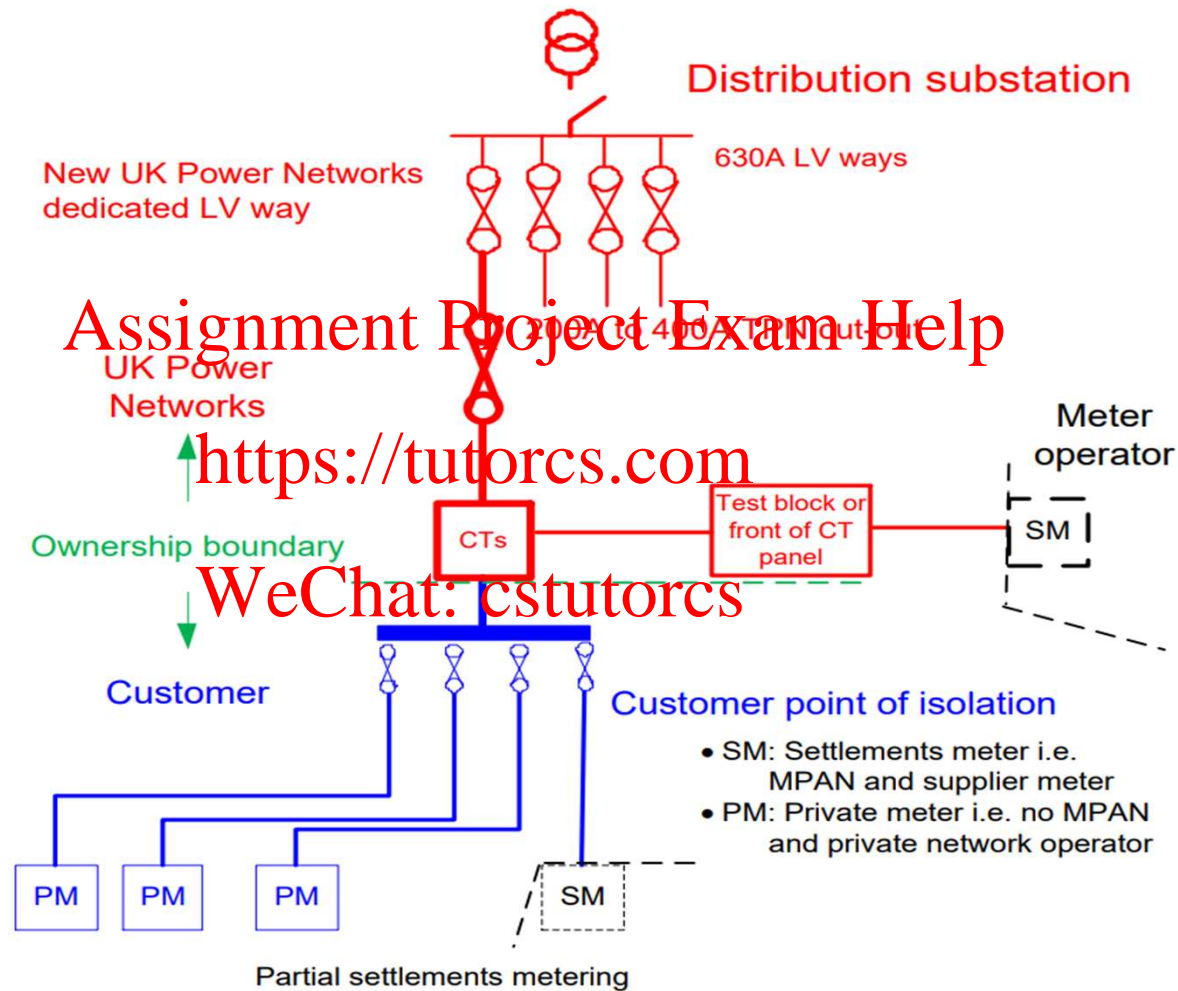
MPR (kVA)	Service Cable	Rating and Termination	Max. Fuse Rating (A)
90 - 138	95mm ² Three-phase Aluminium Waveform	200A Three-phase cut-out	200
139 - 217	185mm ² Three-phase Aluminium Waveform	400A Three-phase cut-out	315
218 - 277	300mm ² Three-phase Aluminium Waveform	400A Three-phase cut-out	400

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EDS 08-2100 LV CUSTOMER SUPPLIES: new supply from substation



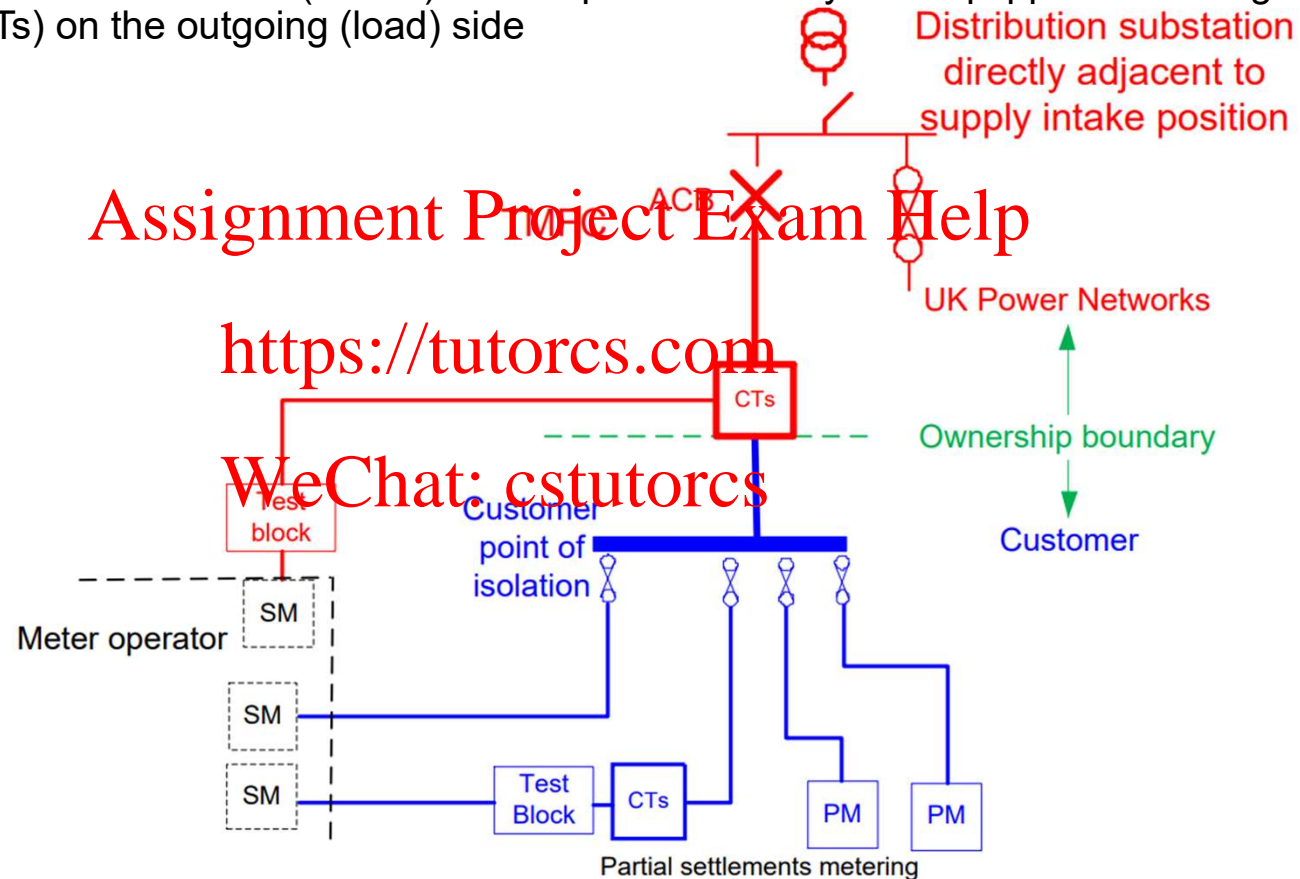
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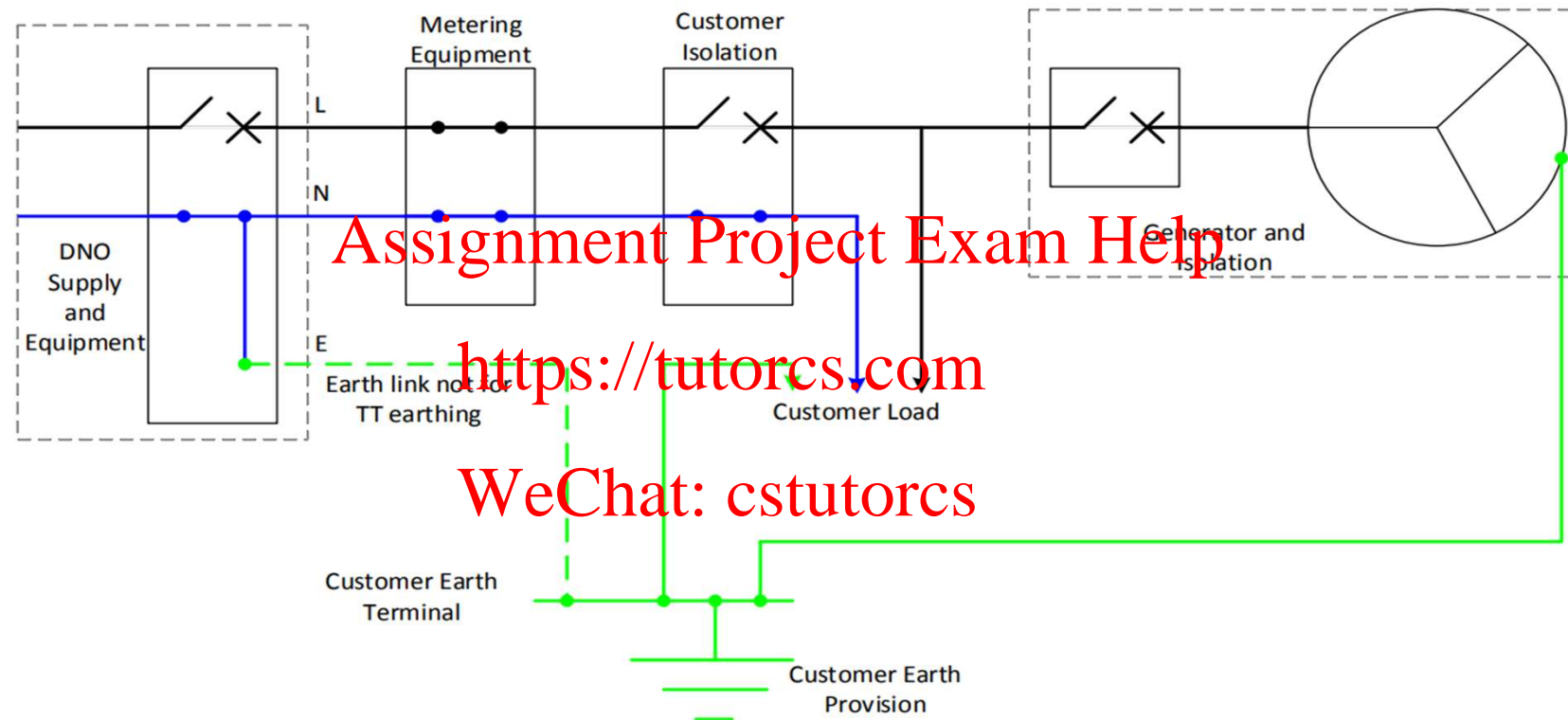
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EDS 08-2100 LV CUSTOMER SUPPLIES (800A – 1440A 3Φ supplies)

- A 800A to 1440A three-phase and neutral (TPN) supply shall be provided via an air-circuit-breaker (ACB) in a 5-way Transformer Mounted Fuse Cabinet (TMFC) with a spare 630A way and equipped with integral metering current transformers (CTs) on the outgoing (load) side

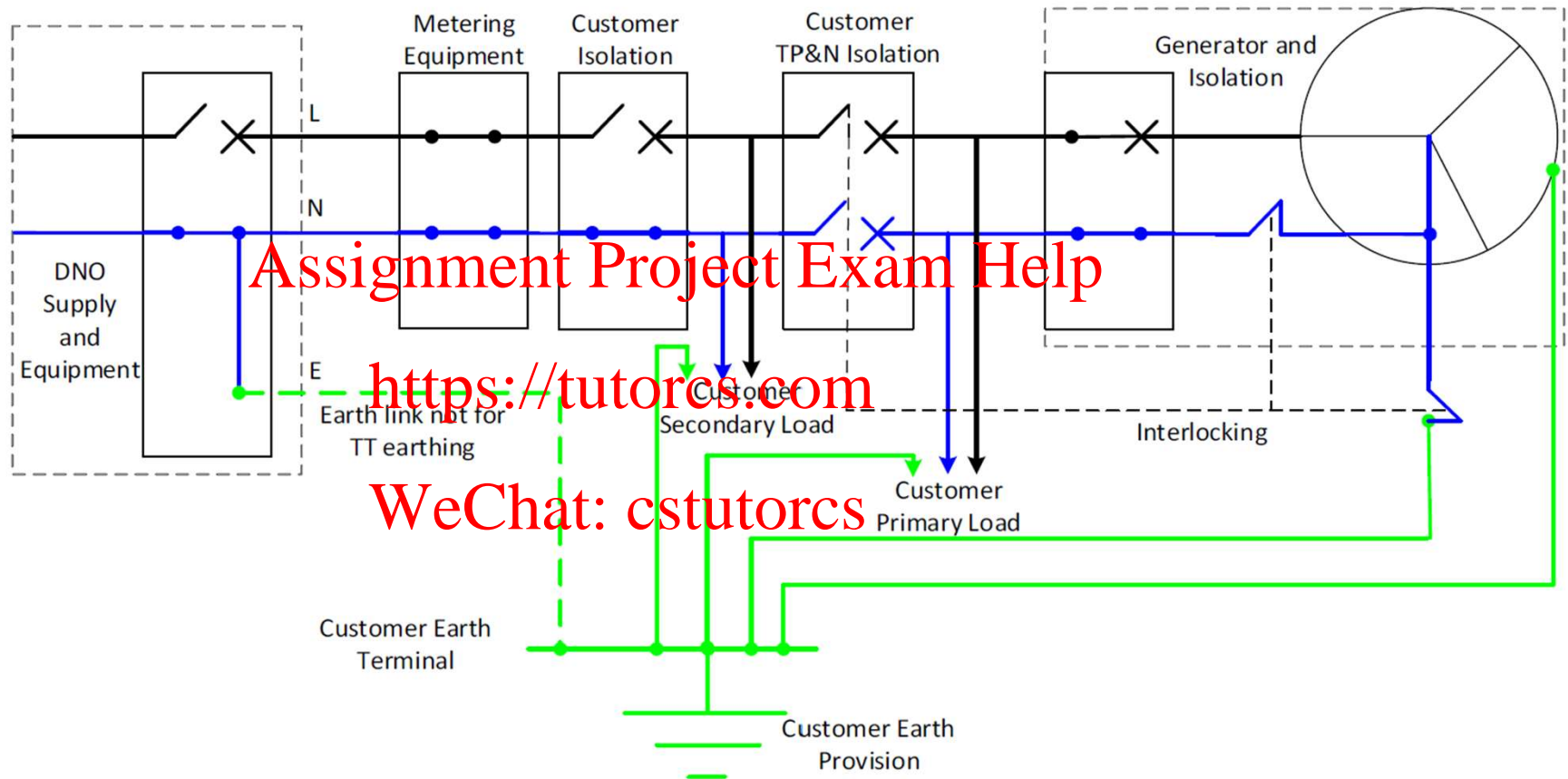


LV Generation for Parallel Operation Only



- Earthing for an LV generator designed for parallel operation only shall be installed in accordance with ENA EREC G99 noting that independent neutral earthing for the generator is not a requirement where there is no application for standby generation.

LV Generation for Parallel and Standby Operation



Earthing for an LV generator designed for both parallel and standby operation shall be installed in accordance with G99.

Q & A

- I specifically wanted to discuss the issues a DNO faces as the UK moves to a lower carbon economy and restricts the use of natural gas and petroleum.
 - Later in the course we will discuss more about EVs, Heat Pumps and other low carbon technologies and their impact on transmission and distribution networks.
 - Most experts expect domestic customers to significantly increase their annual use of electrical energy.
 - Main issue for networks is when people want to use the Energy.
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- My personal view is a “smart” home will install an “Energy Computer” that talks with the Smart Meter, calculating your bill based on time of day pricing. Your computer will then decide based on a “cost & flexibility” optimisation algorithm when to charge the EV or when to operate home heating or cooling. Obviously the decision will also be based on the availability of PV energy and the capacity of your battery “electricity” storage systems and thermal heat/cold storage systems
 - Significant reduction in domestic energy costs is “easily” achievable with new build homes, but major challenges exist with many existing properties.
 - Situation is even worse in the rental sector, but can we imagine a situation where a landlord cannot rent-out a property unless its “Energy Performance Certificate” is an A or B rating.
 - Perhaps something similar is required when you sell your home, i.e. an Estate Agent cannot advertise it, unless the EPC rating is high.
 - UK government commitments/promises/words about a low carbon energy future are impressive, but what will we achieve in the next 5, 10 or 20 years.