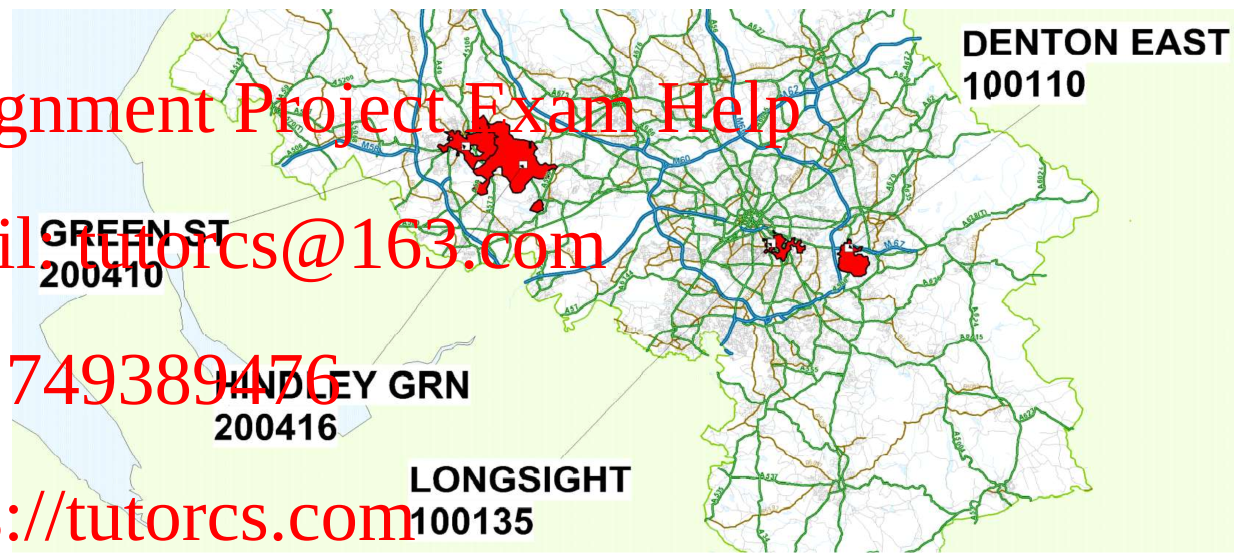
University of Exeter
Centre for Smart Grid

L4 ENGM
HV and LV Distribution Networks: Smart Street Innovation Project

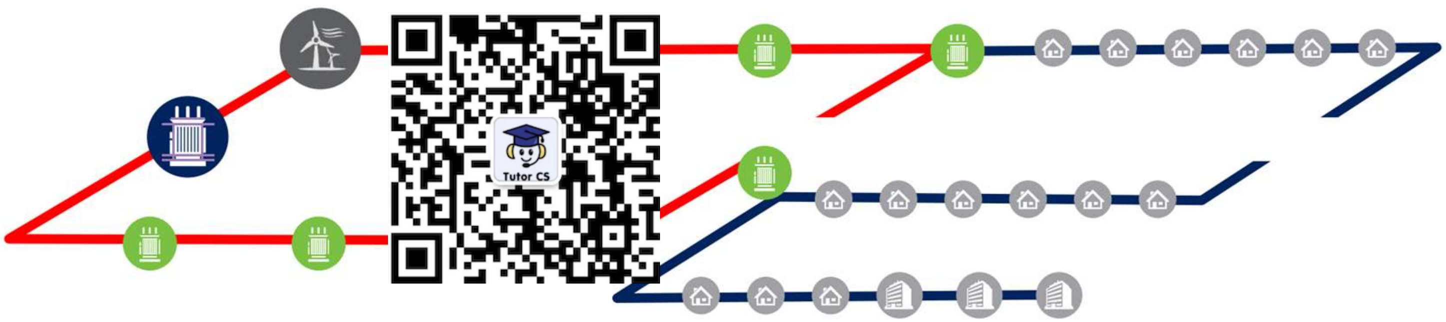
Prof Peter Crossley

- Scenarios studied a variety of Smart Street interventions over a wide variety of demand and generation levels including:
  - Running the HV loops open and closed
  - Interconnecting LV feeders
  - Installing differing sizes of HV and LV capacitors at various positions within the network
  - Employing on-load tap changers at distribution substations



Electricity North West / Smart Street / Network Design Methodology / 31 July 2014

ENW Smart Street: Existing radial network



Network limitations	Customer impact
Diversity between feeders is untapped	Customers' needs invisible to the network
	Demand and generation levels limited by passive voltage control systems
Fuses unable to cope with cold load pick up	Reliability driven by fix on fail

- Existing radial networks have worked well and are reliable and resilient,
- When did you last have a power cut?
- Change is needed because of our low carbon future, ICT capabilities & customer expectations.

ENW Smart Street: Existing radial network

Historic networks have no active voltage regulation

- Figure assumes, heavy load (perhaps winter early evening) and voltage at supply transformer held high (uses capability of tap changer at 33kV:11kV transformer, no tap changers at 11kV:400V transformer).
- As you progress along the LV feeder, voltage drops and supply voltage at last house must be >216V.

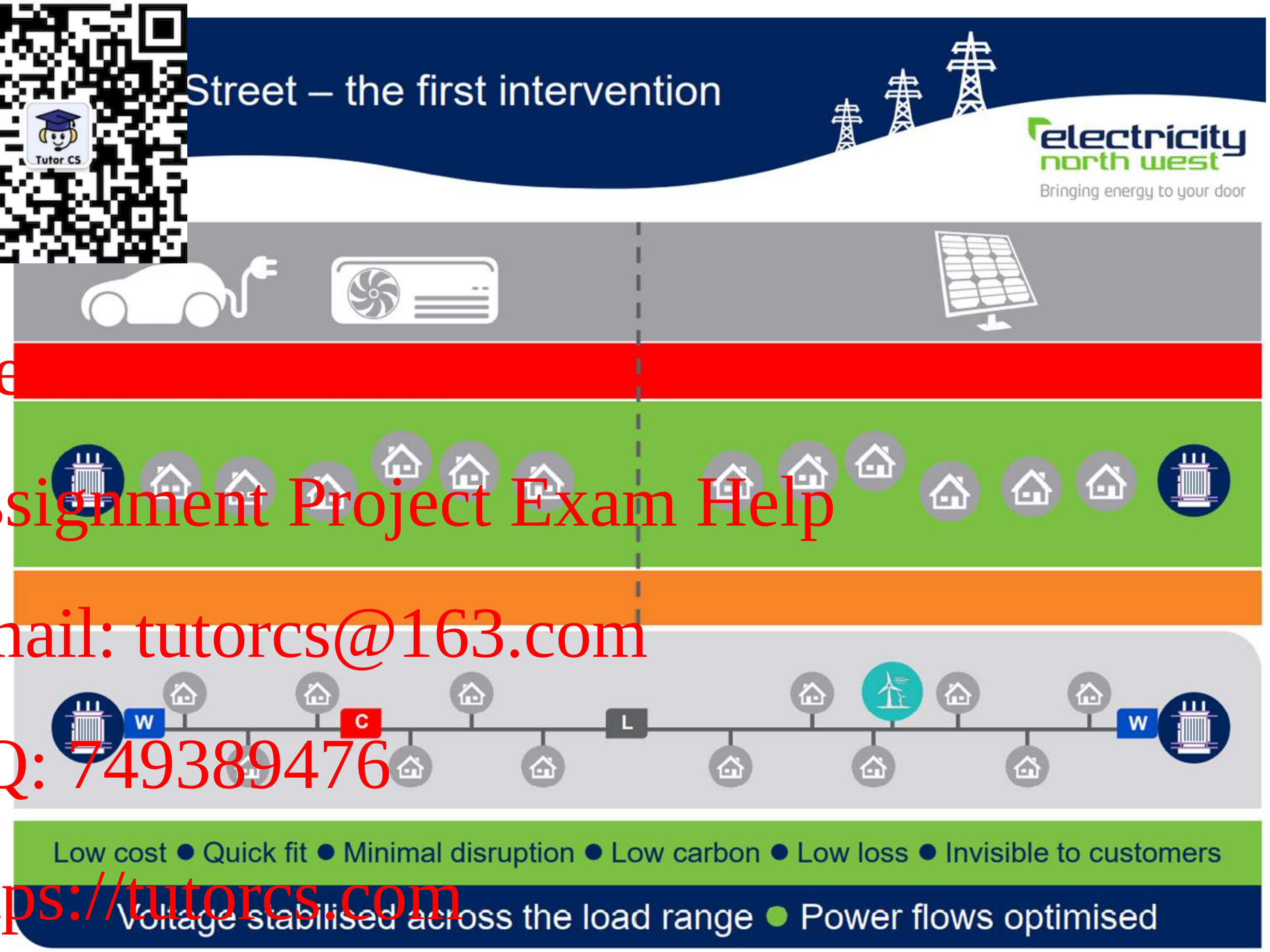
ENW Smart Street:

Heat Pumps & EVs increase demand, hence voltage reduces at end of radial LV feeder, but PV raises the voltage. Ho ure L-N voltage is always between 216V and 253V?

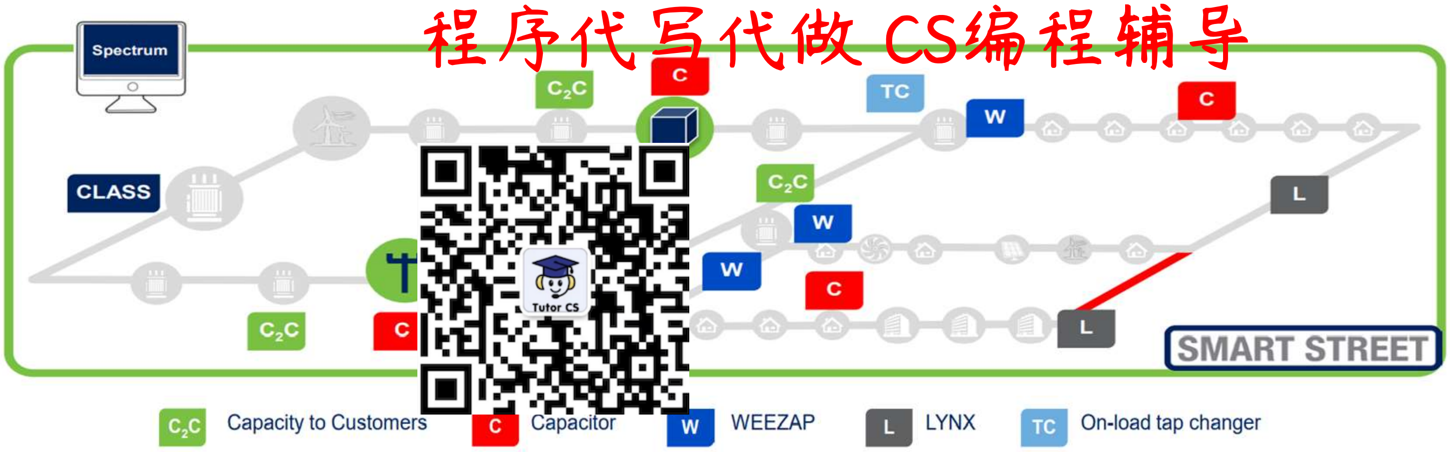
Problem: what happens if transformer supplies two LV feeders, one with heavy demand and one with light demand and PV?

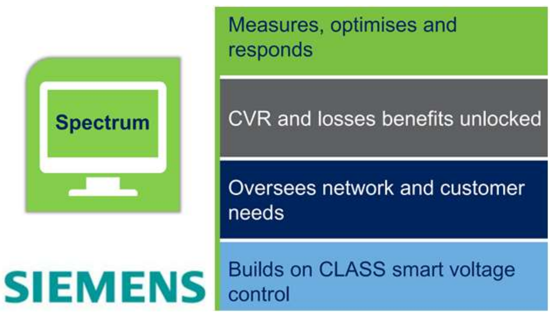
Smart Street:

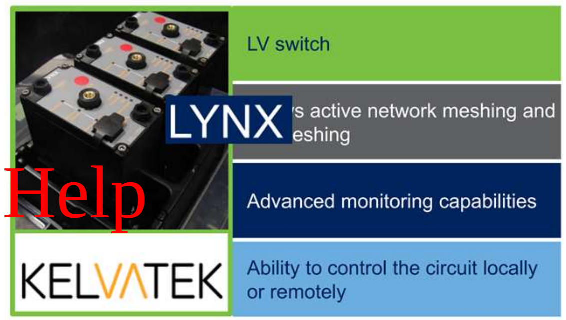
- Smart Street aims to utilise advanced real time optimisation software to simultaneously manage HV and LV network assets to respond to customers' changing demands.



- Voltage management on HV networks will look to reduce network losses while conservation voltage reduction (CVR) on the LV networks will look to reduce energy demand.
- Capacitor banks on the HV network are being utilised to help manage network losses by adjusting the networks power factor.
- On the LV network, a mix of capacitor banks and controlled meshing of networks will be integrated to flatten the voltage profile and improve energy efficiency.
- Meshing of LV networks will also aim to release additional network capacity.





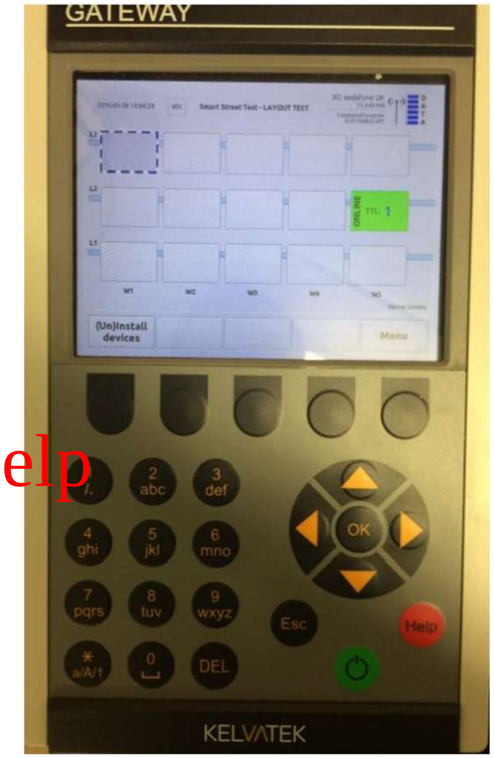


- Distribution Network CVR is reduction of energy consumption resulting from decrease in voltage.
- Smart Street will optimise voltage by utilising on-load tap changing (OLTC) transformers.
- These transformers regulate the voltage along the feeder while maintaining statutory limits.
- Allows peak load to be reduced, hence reducing the annual energy consumption.
- Additionally Smart Street will utilise shunt capacitors on the LV feeders to allow for a voltage boost at the end of the circuit to reduce voltage drop. This will allow for a flatter voltage profile, allowing for the OLTC to tap closer to the lower limit.

Siemens Spectrum 5: Actively helps grid operators manage, orchestrate and optimize distribution systems, fosters the grid integration of renewables and electromobility, and boosts efficiencies, all while maintaining a stable and reliable power supply.

ENW Smart Street: Kelvatek LV vacuum technology

- Weezap is an LV vacuum circuit bre fitted directly onto an existing LV fus in place of an existing fuse carrier.
- Device has the ability to open and cl circuit locally or remotely while provi protection against overload and fault conditions.
- It will have the ability to communicate to the control room via onsite Gateway devices allowing remote monitoring and control.
- Up to 15 Weezap devices can be connected to one Gateway device and up to two Gateways can be commissioned in any one location.



- What are the cyber implications of Weezap?
- It operates as a smart "communication aided" replacement of an LV fuse.
- A fuse had to replaced by a human if it blew causing a delay in supply restoration of a few hours.
- Opening and closure of the "Weezap" circuit can be performed locally or remotely, fast supply restoration.
- How secure are the communications linking Weezap to the ENW control centre or the Spectrum 5 (NMS).

ENW Smart Street: Kelvatek LV vacuum technology

- Lynx is an LV vacuum switch desi... ly into existing LV link boxes in place of s...
- Device has ability to open and clo... box either locally or remotely.
- Gateway device will allow remote monitoring and control.

- Whilst the Lynx devices does not have inbuilt protection functionality they are designed to open on a loss of volts, sectionalising the LV circuit under fault conditions.

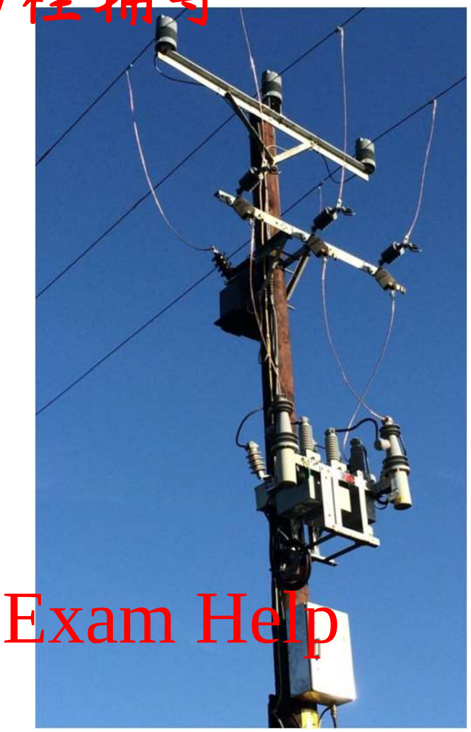
- Weezap and Lynx are able to measure circuit voltage, current, power factor, real power, apparent power, reactive power, frequency, total harmonic distortion (THD), and individual harmonics including magnitude and phase.
  - Data intervals can be configured to calculate the mean values over a range from one minute to one hour.

Electricity North West/Smart Street/Voltage and Configuration Optimisation/20 February 2017

ENW Smart Street: Voltage Support (Capacitors)

- Trials employed 84 LV capacitors t... boosts on distribution circuits when requ...
- Five units are located at distributi... nd the remaining 79 are installed on the LV feeders in line with the Smart Street network design methodology.

LV capacitor installation, Denton East.



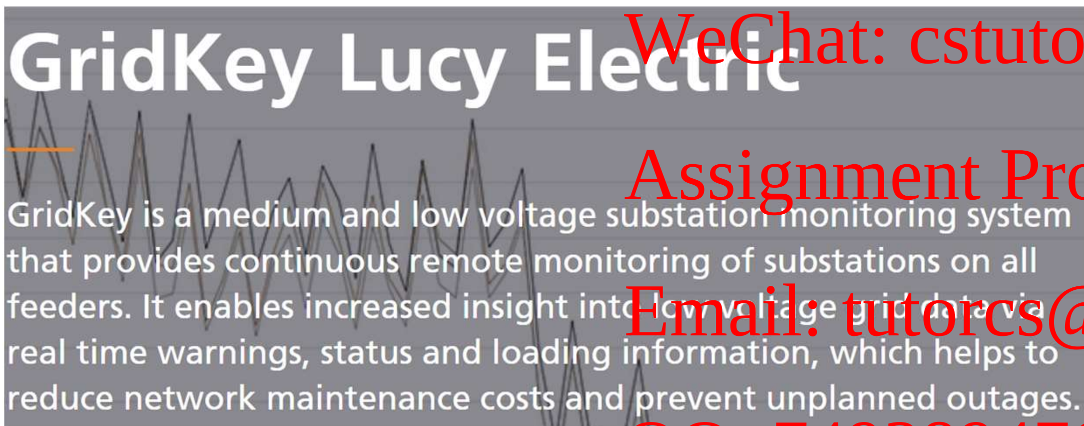
- Trials employed six capacitors on HV network to allow for reactive compensation.
- 3 ground-mounted capacitor units and 3 pole-mounted units are installed on HV rings.
- Capacitor banks are designed to have reactors in series to lower the resonance below critical order harmonics.

ENW Smart Street: Efacec On-Load-Tap-Changing HV:LV Transformers

- Five distribution transformers f[illegible]n-load tap changers are installed at distribution substations and operate via an automatic [illegible]elay (AVC).
- The Spectrum optimisation so[illegible]cates with the AVC and alters the voltage set points to allow the transformer to switch to th[illegible]etting.

ENW Smart Street: Gridkey End-Point Monitoring (EPM)

Monitoring units are inst[illegible] of any radial LV feeders at the point of the highest calculated voltage drop, [illegible]t measurements for voltage optimisation purposes and to validate network [illegible]s during the research phase of the project.



EPM installation, Denton East.

ENW Smart Street: Siemens Spectrum 5 Software

- Optimisation software is part of the [illegible]er system developed by Siemens.
- SP5 will manage and control variou[illegible]d on calculated load flow analysis.
- Spectrum is responsible for optimis[illegible] LV & HV networks in terms of voltage optimisation and network configuration.

Grid C[illegible]h Spectrum Power | Energy automation and smart grid | Siemens Global

We build our Spectrum Power solution[illegible]h-performance technology platform, with one common user interface, one common network mode[illegible]f applications.

With Spectrum Power, you'll gain the greatest possible return on investment through

Flexibility – easily adaptable to emerging and continually changing regulatory requirements through modularity and step-by-step extensions

Openness – to new Smart Grid business cases and to easy interoperability with any enterprise IT

- Siemens Adapter Framework (SAF)
- Proven SOA and web service capabilities
- CIM (IEC 61968) compatibility

Efficiency – eliminate redundant data modeling and reduce data maintenance efforts through central data management based on CIM (IEC 61970). The automatic generation of network displays significantly minimizes the workload associated with manually building displays.

Cybersecurity – always up-to-date and in conformance with international IT security standards

ENW Smart Street: Remote Terminal Units

CG Remote Terminal Units act a[illegible]entrator and router collating the information from the Weezaps, Lynx, EPMs and HV a[illegible]or banks and passing it on to either SP5, CRMS or both as appropriate.

They also pass controls from the two systems back to the required device.

- CG Distributed RTUs are intended for distributed control and monitoring in critical environments where a false operation is unacceptable.
- Units are housed in small wall-mounting outdoor enclosures, with a fixed point count discreet I/O hardware interface to the utility's field wiring.
- DRT central processors use the same operating system as the ePAQ and STN series 6CPP6 processor, and are configured with the CG Automation's same interactive, Windows based, ConfigWiz-Plus® program.

ENW Smart Street: Network Management & Control

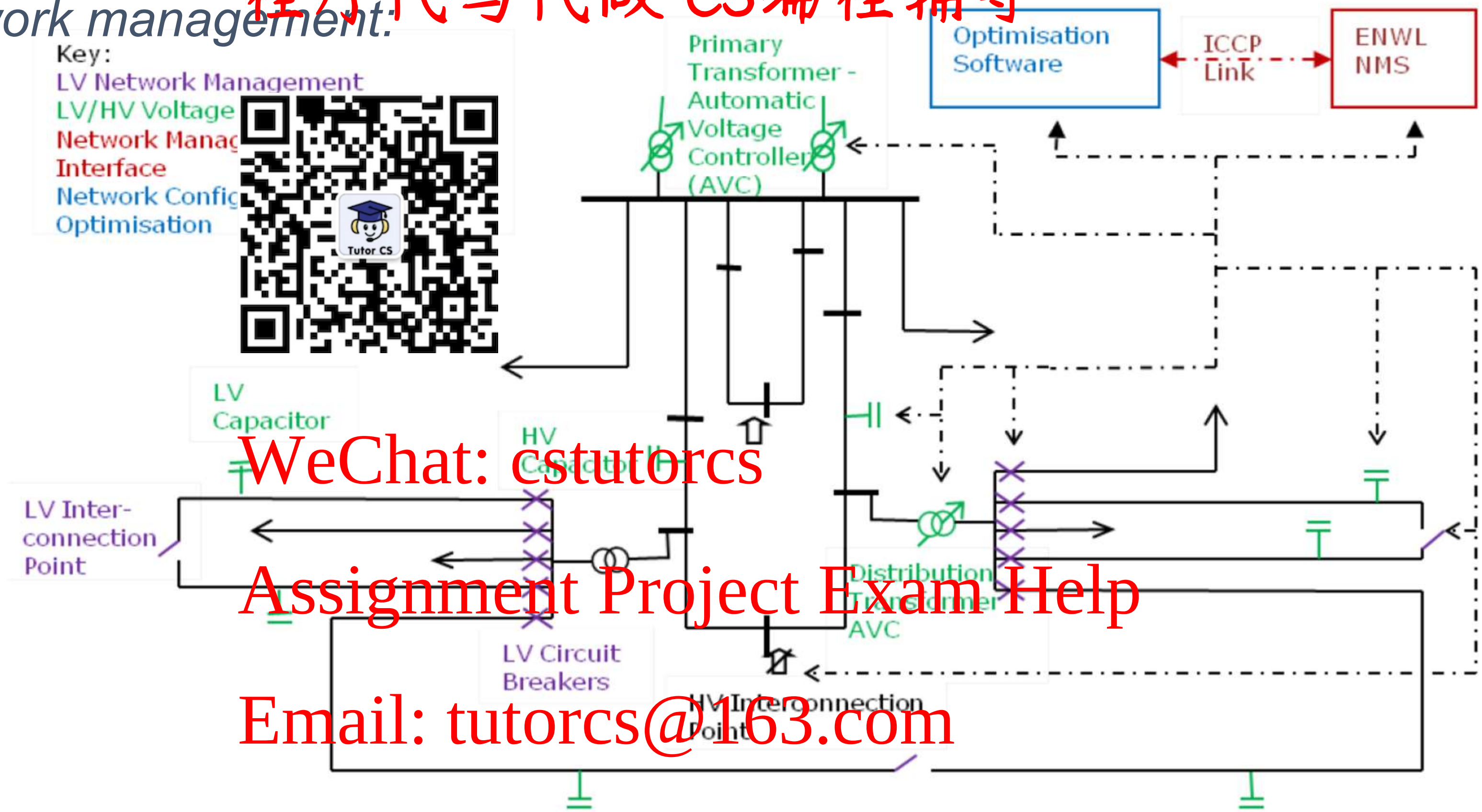
- Electricity North West's existing communicates with the optimisation software using an inter control communications pr link which has been developed specifically for Smart Street.
  - allows all network configuratior be controlled via the NMS which will be overseen by trained control engineers.
  - allows control staff to react to a which are indicated as an alarm within both Spectrum and the NMS.

- Recently Electricity North West replaced its old Control Room Management System (CRMS) with a state-of-the-art NMS.
- The new NMS provides increased visibility of network operation coupled with dynamic control to optimise the configuration of the network at any given time.
- It has incorporated, and improved, automatic supply restoration algorithms from the old CRMS, delivering improved security of supply.
- Its outage management system provides efficient management of field teams and up-to-the-minute customer information.
- Central to the development of our NMS is the necessity to have an accurate representation of the network.
- We have completed a comprehensive cleanse of our asset information and established a single geospatial asset management system.

ENW Smart Street Trial and Test Regime:

Smart Street trial	Test r[illegible]
LV voltage control	1. On[illegible]ng distribution transformer only
	2. On[illegible]ng distribution transformer and capacitor(s) on LV circuits
	3. Ca[illegible]bution substation only
	4. Capacitors at distribution substation and on LV circuits
	5. Capacitor(s) on LV circuits only
LV network management & interconnection	1. LV radial circuits
	2. LV interconnected circuits
HV voltage control	1. Voltage controllers at primary substation only
	2. Voltage controllers at primary substation and capacitor(s) on HV circuits
HV network management & interconnection	1. HV radial circuits
	2. HV interconnected circuits
Network configuration & voltage optimisation	1. Losses reduction
	2. Energy consumption reduction

Smart Street network management:



- Figure shows how various Smart Street technologies will be installed across trial networks.
- Optimisation for violations, losses and to minimise load as a single VVC function.
- Opportunity to mesh networks also included, but radial configurations preferred running arrangement.
- Switching equipment shall be closed (create loop or mesh networks) if the objective-function results in positive changes to the network above a set threshold.

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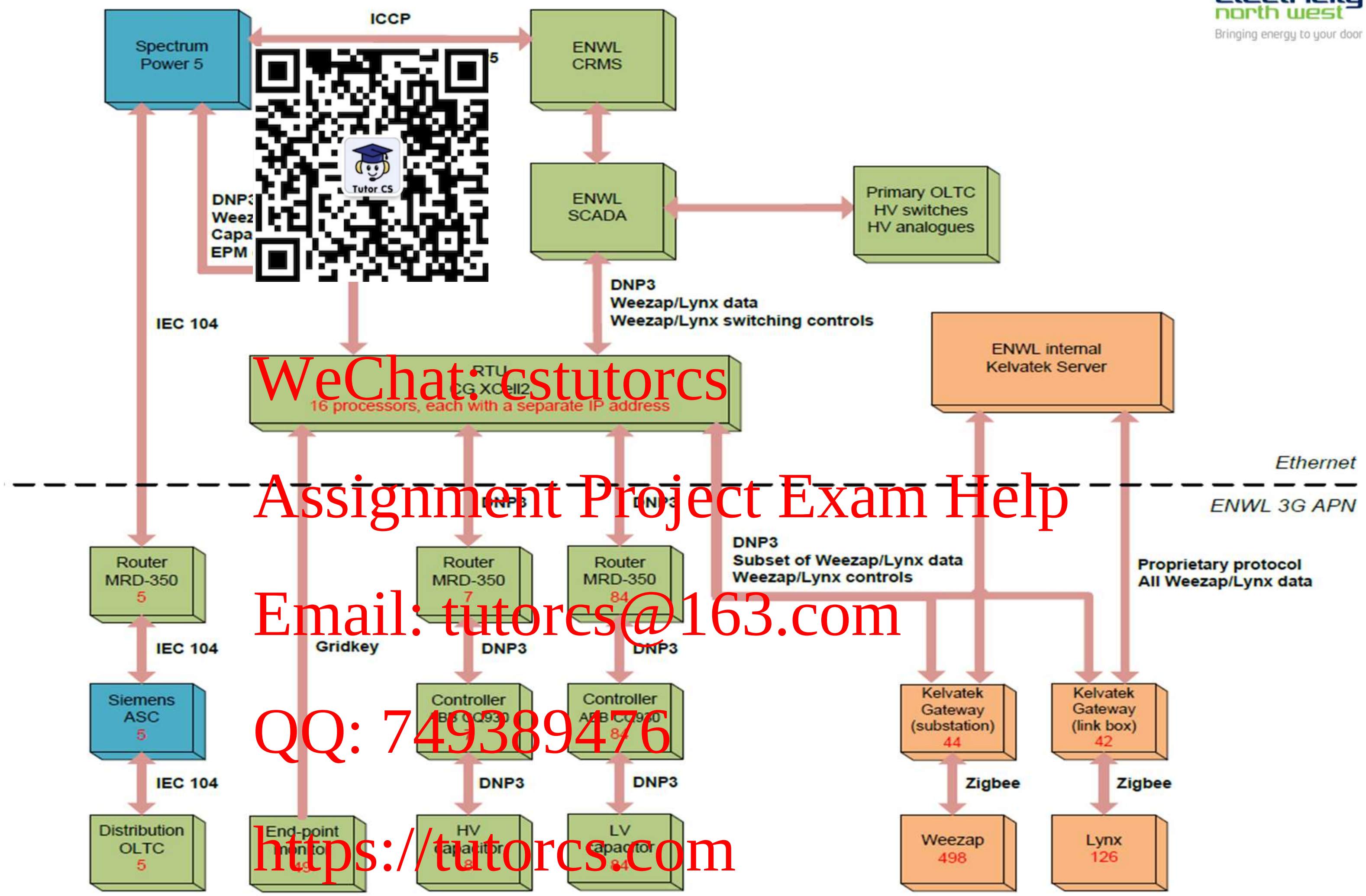
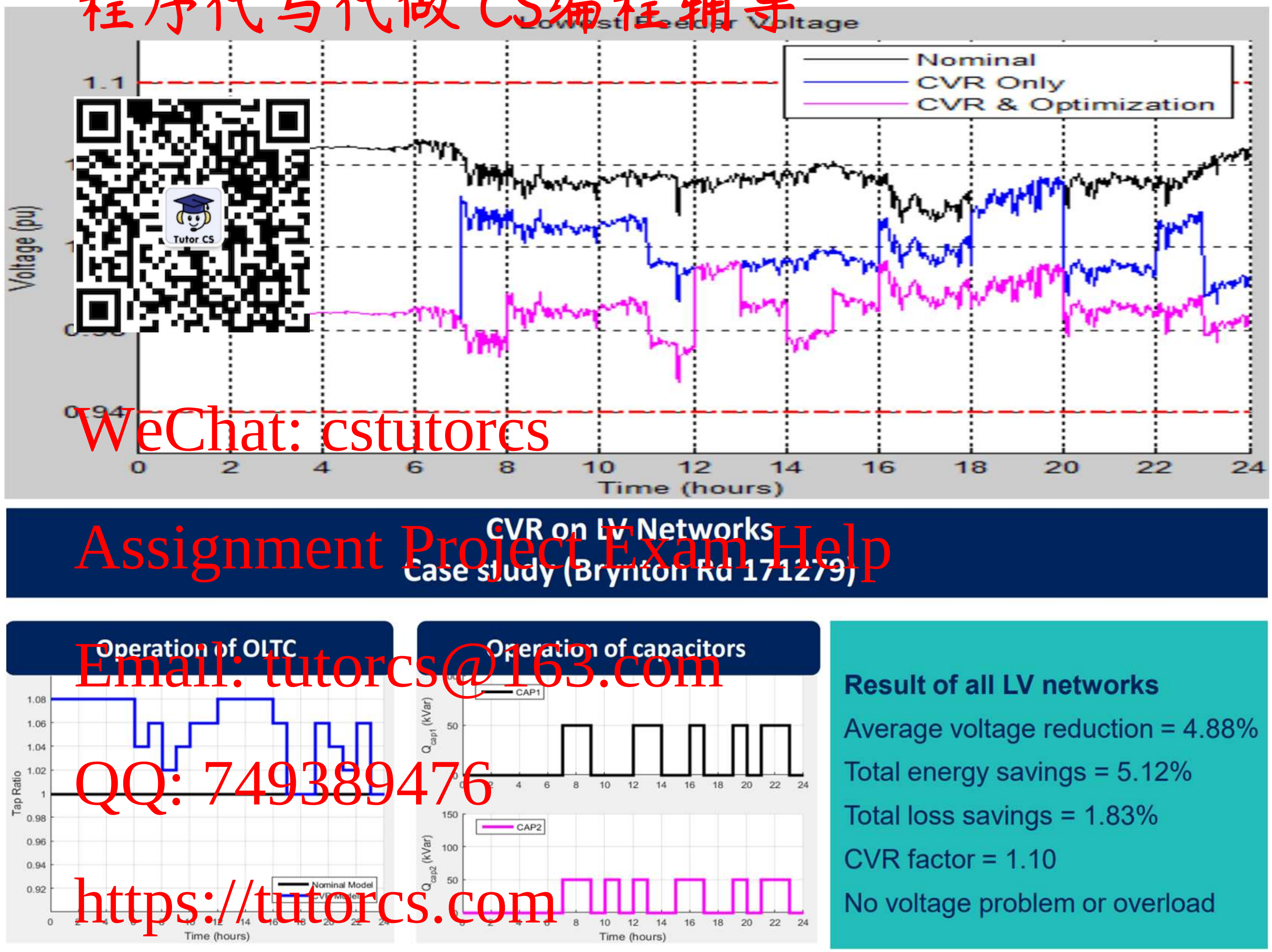
ENW Smart Street: Communication Architecture

electricity north west
Bringing energy to your door



ENW Smart Street:



ENW Smart Street:

Now we can stabilise vo

We can set the voltage

This will lead to:

- Reduced demand
- Reduced customer energy consumption
- Maximised DG output

How much could customers save?		GB
Reinforcement savings via DUoS	£330 over 25 years	£8.6b over 25 years
Reduced energy consumption, 2013 (from CVR ≈ 3 - 7%)	£15 - £30 pa	£390 - £780m pa
Maximise DG output (from maximising Feed In Tariff income)	£70 pa	£20m pa

Personal View: slide is optimistic, if you lower voltage from 240V to 220V, it takes longer to cook your food, boil your kettle and thermostatically controlled heating systems stay on for longer. In addition most IT equipment is a constant power load operating using DC, hence as voltage drops, current increases and losses increase. Expect annual domestic savings are negligible. However, “probably” reduces reinforcement costs required to deliver Net-zero world with PV, EVs and Heat Pumps.

ENW Smart Street: Conservation voltage reduction (CVR)

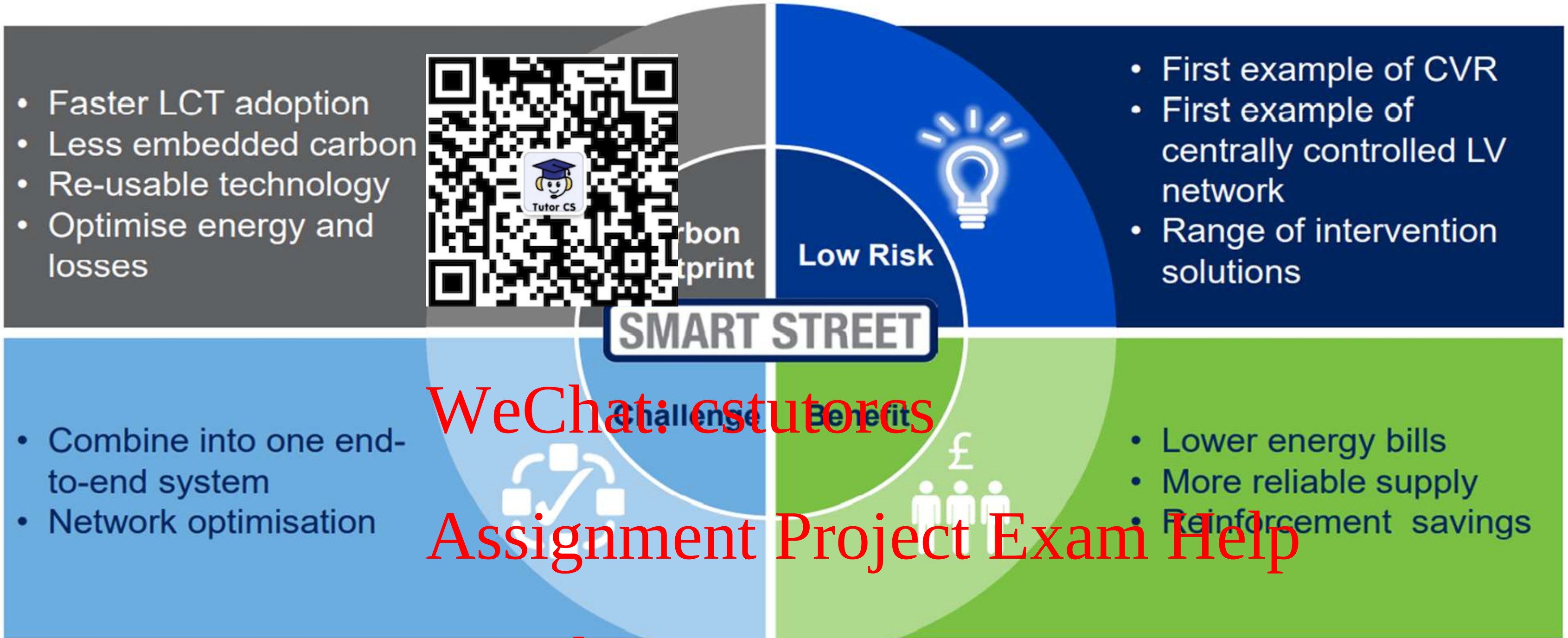
Smart Street, HV and LV V[illegible]ion Optimisation Study, 20 February 2017

- Electrical equipment made for the [illegible], including household appliances and lighting, is designed to operate most efficiently in the regi[illegible]V.
- Equipment can, operate adequatel[illegible]he region of 200V. If power is delivered at voltages higher than these optimum levels, then energy [illegible]ntly wasted.
- Excess voltage can shorten the useful life of electrical equipment, since the excess energy is dissipated as heat.
- Therefore optimising network voltages reduces overall energy consumption, improves power quality and extends the life of the customer's equipment.
- Smart Street proposes to optimise network voltages by using CVR on the LV trial networks.

Personal View:

- Sceptical about the above statements, I do not believe the average domestic consumer will save significant kWh on electrical consumption by a DNO ensuring a house is always supplied at 220 – 230V.
- Companies that supply house level or appliance devices that reduce the incoming mains voltage to 220V, tend to emphasise over optimistic claims on their adverts and web sites.
  - extreme examples are voltage optimisation devices for kettles, at a lower voltage it takes longer to reach boiling point and the kettle dissipates more heat, hence required electrical energy (kWh) increases. Recommend boiling correct amount of water.

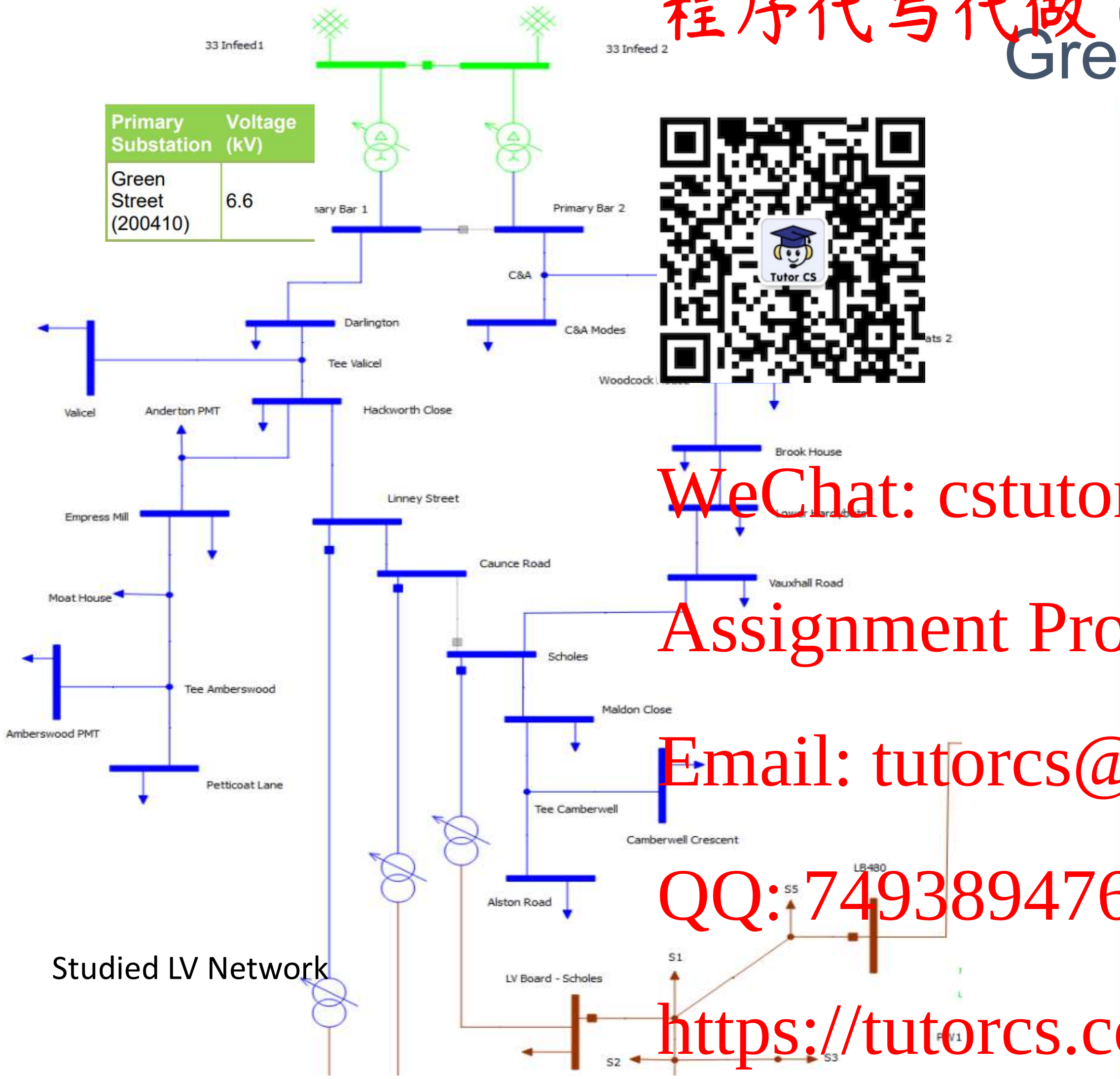
ENW Smart Street:



- What are the cyber security implications of a centrally controlled LV network?
- Can the power industry design, build and operate a resilient and reliable internet based cyber control system that evolves with time and monitors and controls all aspects of the power plant used in LV and HV networks:
  - transformer tap-changes, switching of capacitor banks, opening and closure of network switches to deliver flexible “meshed and unmeshed” networks and perhaps even direct utility control of demand & generation.
- Are domestic customers ready for a smart low-carbon electricity dominated future?

Green Street IPSA model

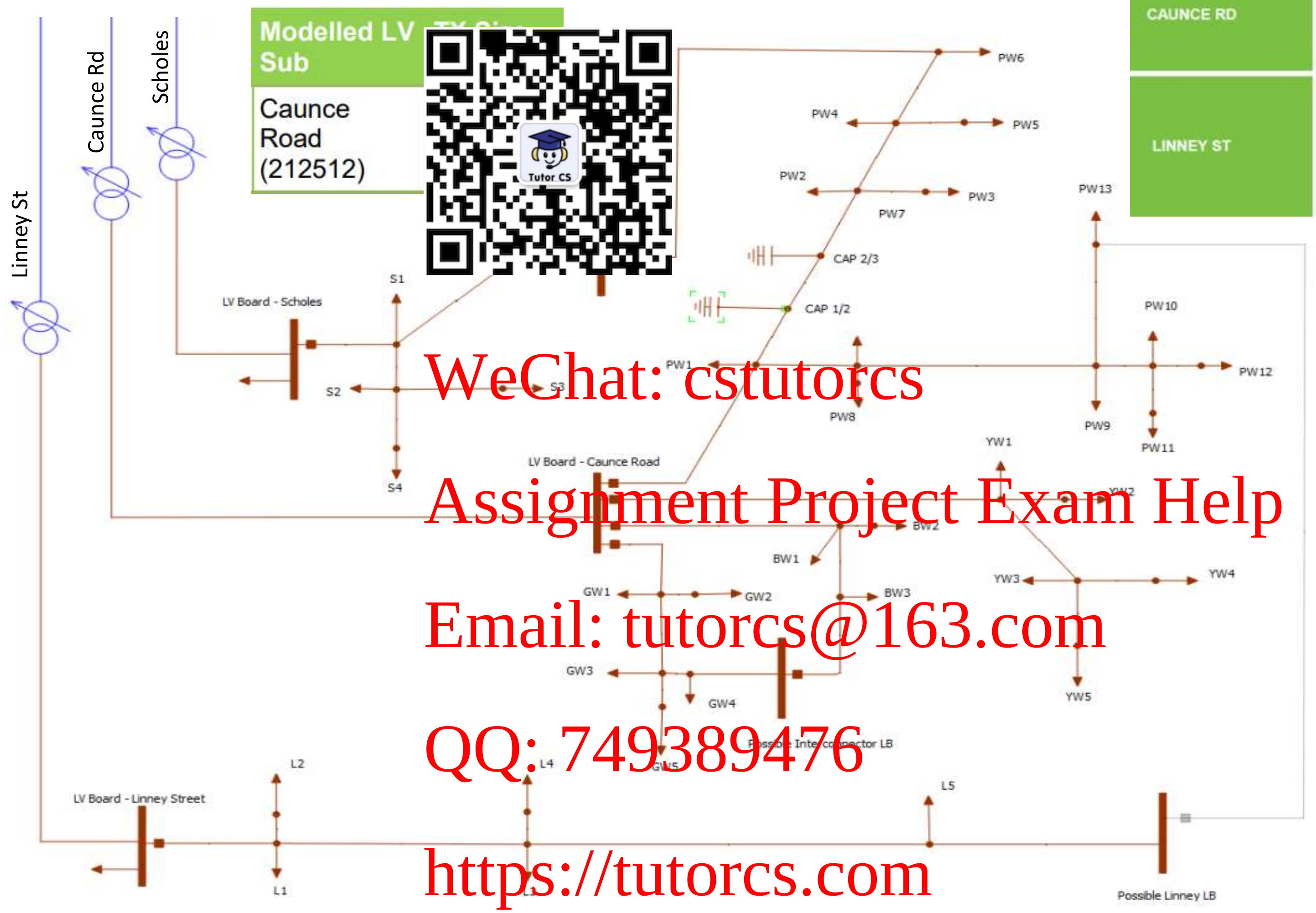
Primary Substation	Voltage (kV)
Green Street (200410)	6.6



GREEN STREET		
	CAMBERWELL CRES	LV Way 2 - Nearside Camberwell Crescent North
		LV Way 3 - Farside Camberwell Crescent North & Link Box
		LV Way 4 - Farside Camberwell Crescent South & Link Box
		LV Way 5 - Nearside Camberwell Crescent South
	CAUNCE RD	LV Way 2 - Blocks 12/16 -20/22/23
		LV Way 3 - Blocks
		LV Way 4 - Blocks to LB480 Scholes Street (assumed)
		LV Way 5 - Blocks
	LINNEY ST	LV Way 2 - Scholes B2
		LV Way 3 - Scholes B2
		LV Way 4 - Linney St
		LV Way 5 - LB Schofield Ln
		LV Way 7 - Lorne St
	MALDON CL	LV Way 2 - Link Box Shildon Close
		LV Way 3 - Link Box Wilston Ave
		LV Way 4 - Link Box Camberwell Cres
		LV Way 5 - Link Box Bamford Dr
		LV Way 6 - New School
	MOAT HS ST	LV Way 2 - LB535 Manchester Rd
		LV Way 4 - Dobson Park Way
	PETTICOAT LN	LV Way 2 - Thirlmere Ave
		LV Way 3 - Link Box 528 Windermere Rd
		LV Way 4 - Link Box 526 Kendal Rd
		LV Way 5 - Coniston Ave/Derwent Ave
		LV Way 6 - Haweswater Ave
	VAUXHALL RD	LV Way 2 - Vauxhall Rd Flats
		LV Way 3 - LB480 Belvoir Court (Hackworth Cl (RR30))
		LV Way 5 - Shopping Precinct
		LV Way 6 - School
		LV Way 7 - Vauxhall Rd

LV network: Linney Street, Caunce Rd & Scholes

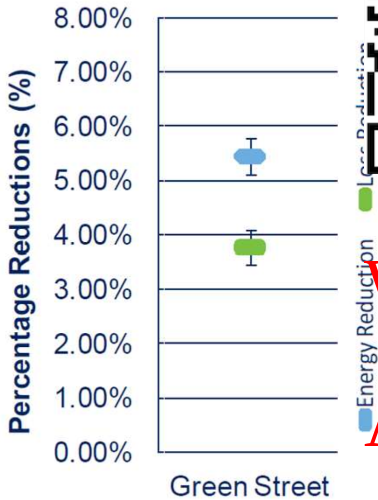
CAUNCE RD	LV Way 2 - Blocks 12/16 -20/22/23
	LV Way 3 - Blocks
	LV Way 4 - Blocks to LB480 Scholes Street
	LV Way 5 - Blocks
LINNEY ST	LV Way 2 - Scholes B2
	LV Way 3 - Scholes B2
	LV Way 4 - Linney St
	LV Way 5 - LB Schofield Ln
	LV Way 7 - Lorne St



UoM carried out four case studies using the CVR model

Results for HV Green St and 7 of its LV feeders are below:

Energy & loss reduction on HV Green Street using CVR



Energy and loss reduction on LV networks using CVR model

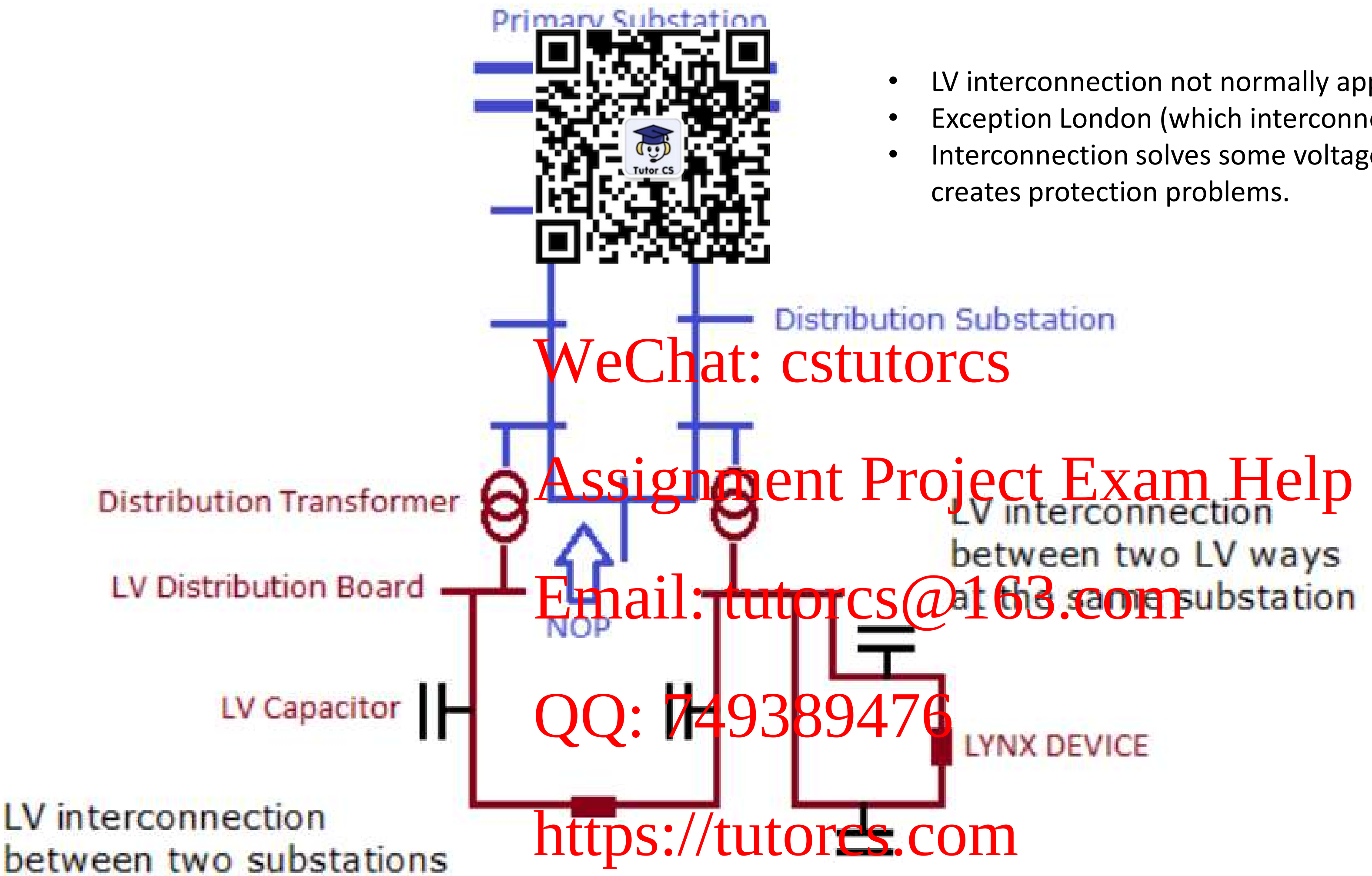
- According to simulation results CVR provides energy and loss savings for all LV & HV networks.
- On an LV network energy consumption and losses reduced by up to 8% and 2.8% respectively.
- On an HV network reductions are 7% in energy consumption and 5% in energy losses.

Each 1% voltage reduction on LV network delivers about 1.05% energy savings and 0.38% energy loss savings
Each 1% voltage reduction on HV network delivers about 1.09% energy savings and 0.72% energy loss savings.

Electricity North West/Smart Street/Voltage and Configuration Optimisation/20 February 2017

Impact on LV voltages of interconnecting LV networks

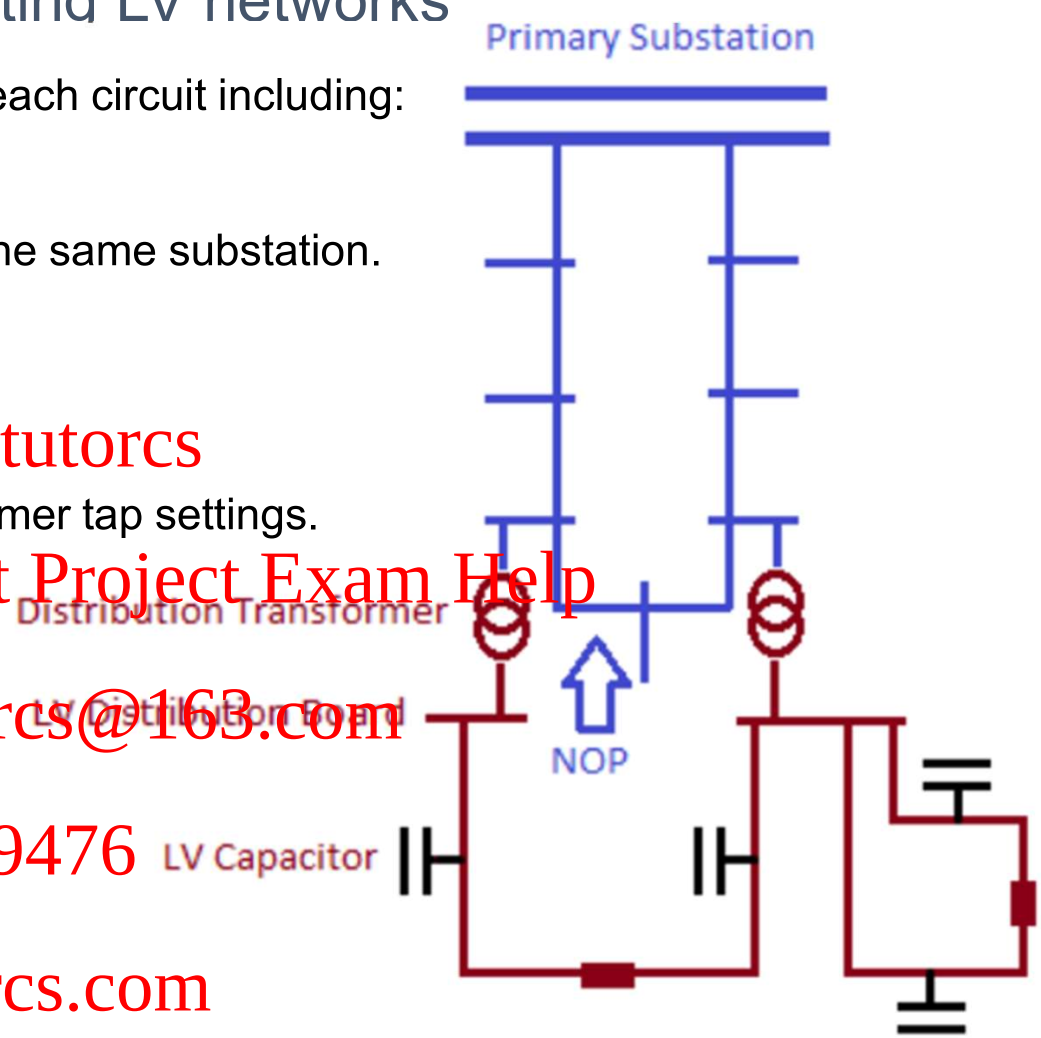
- LV interconnection not normally applied in UK.
- Exception London (which interconnects using fuses).
- Interconnection solves some voltage problems but creates protection problems.



Impact on LV voltages of interconnecting LV networks

A number of operational scenarios … to each circuit including:

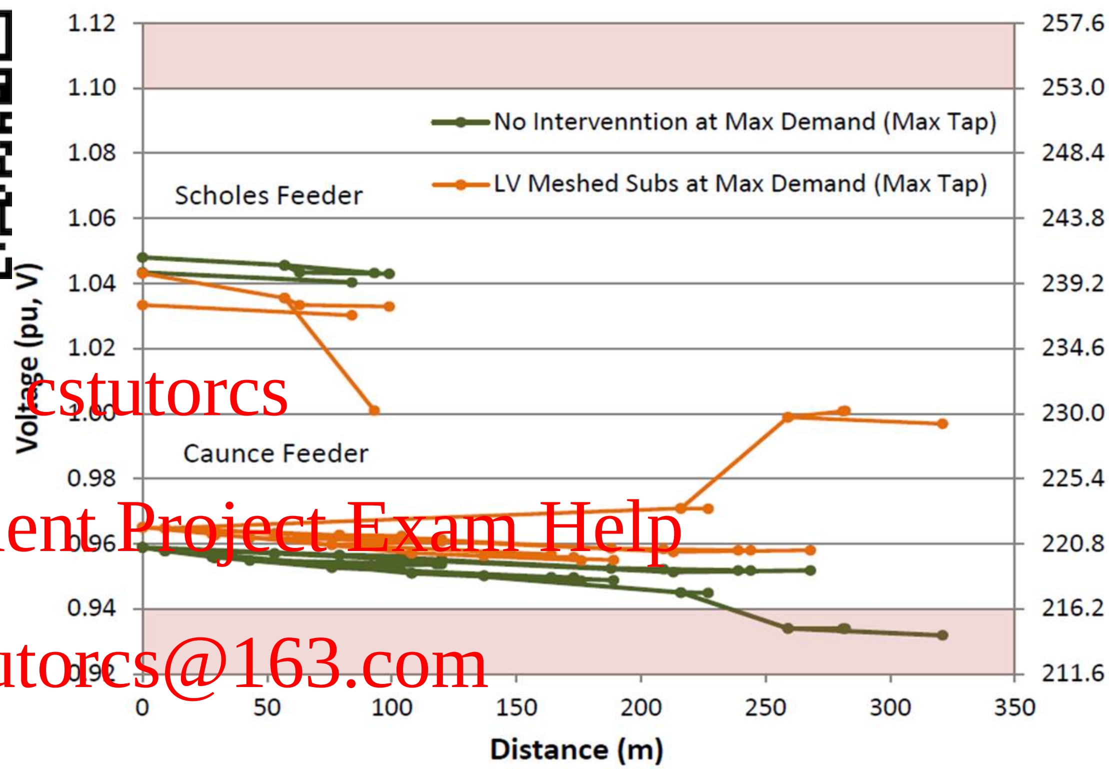
- No intervention (base values).
- LV interconnection between tw…
- LV interconnection between tw… of the same substation.
- LV capacitors at 1/2 the length … er.
- LV capacitors at 2/3 the length of the LV feeder.
- 100kVAr, 150kVAr and 200kVAr capacitors.
- HV ring open and closed.
- Minimum, mid and maximum distribution transformer tap settings.



Green Street, Caunce Road circuit Voltage Profiles:

- Caunce road circuit has a PV pen[illegible]nd 40% (91 customers of the total 226 customers currently have PV installed).
  - On average these installations a[illegible]W.
  - Capacitors were positioned on t[illegible] to the interconnection between substations and the calculated volt-drop on this feeder.
  - The total length of this feeder is 321m to the end node.
- Node PW5 shows largest volt-drop which falls slightly out of the statutory limits (214.33 volts) when the transformer taps are set at +5% during maximum demand with no PV penetration.
- Voltage drops to 213.96 volts under the same conditions when the HV ring is closed.
  - This is due to a slight imbalance of impedances and loads between the two HV circuits.
  - All other measured nodes stay within limits under these conditions.
- In both instances, interconnecting the LV network in parallel with the adjacent substation brings the voltage back within limits.
- Meshing two ways from the LV board shows very little difference in the voltage profile at all measured nodes.
  - Because both radials are evenly loaded with around 30 customers each with an even number of PV installations (circuits also have similar impedances).

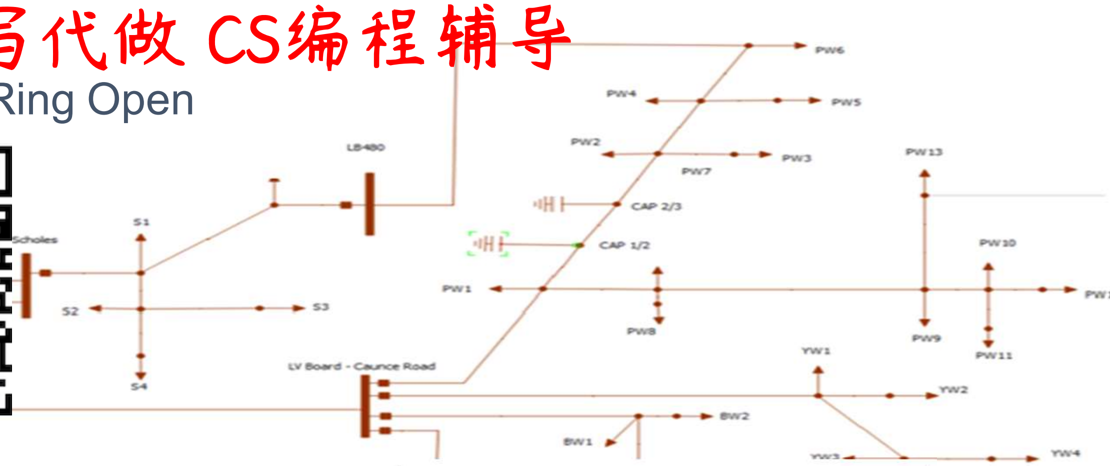
Green Street, Caunce Road circuit Voltage Profiles:



- Figure shows the comparison of the voltage profiles on the PW feeder for the no intervention scenario (green) against meshing the Caunce Road and Scholes substations (orange).
- Results show meshing the two substations flattens the overall voltage profile while keeping the circuit within statutory limits.
- Two feeders see a voltage balance of around 230 volts at the point of interconnection. .

Caunce Road Circuit Voltage Profiles: HV Ring Open

6.6kV HV network from Green
normally operated as open rin

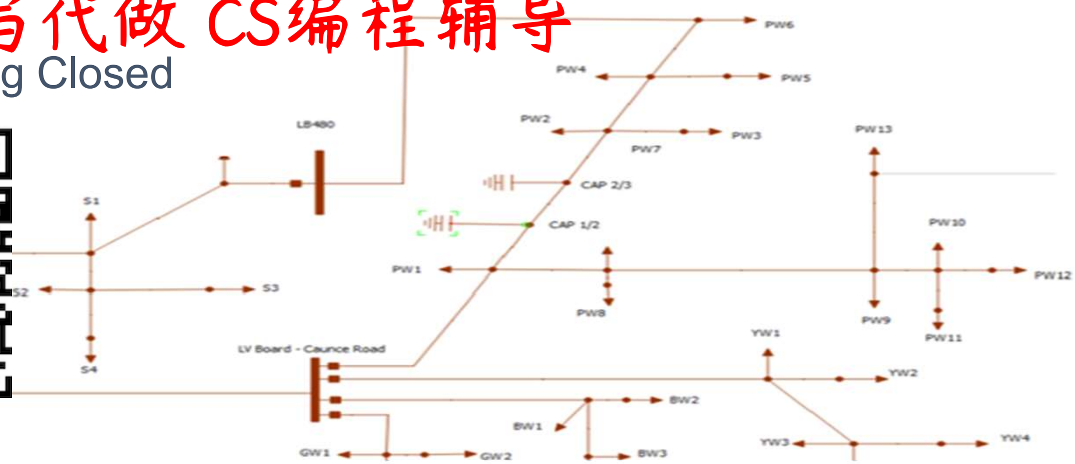


Min Demand of 0.2kW _ (2.28kW PV average installation)

	Scenario	Voltage Level at 0% PV Penetration					Voltage Level at 40% PV Penetration				
		PW5	PW12	BW3	GW5	YW4	PW5	PW12	BW3	GW5	YW4
HV Ring Open & OLTC top-tap +5%	1. No Intervention	226.46	226.98	227.02	227.05	226.95	230.54	229.16	228.94	228.87	229.16
	2. LV Meshed Subs Only	238.57	228.27	228.16	228.19	228.09	240.74	230.49	230.14	230.08	230.37
	3. LV Meshed Ways Only	226.48	226.99	227.05	227.06	226.97	230.54	229.16	228.93	228.88	229.16
	4. LV Meshed Subs & Ways Only	238.41	228.22	228.14	228.16	228.07	240.74	230.49	230.14	230.08	230.37
	5. 100kVAr Capacitor 1/2 Only	229.46	228.78	228.74	228.77	228.67	233.51	230.96	230.66	230.60	230.88
HV Ring Open & OLTC mid-tap 0%	1. No Intervention	237.89	238.38	238.42	238.45	238.35	241.77	240.46	240.26	240.20	240.47
	2. LV Meshed Subs Only	243.22	239.09	239.06	239.09	238.99	245.37	241.18	240.94	240.88	241.15
	3. LV Meshed Ways Only	237.89	238.38	238.43	238.44	238.35	241.77	240.46	240.25	240.20	240.47
	4. LV Meshed Subs & Ways Only	243.26	239.10	239.08	239.10	239.01	245.37	241.18	240.93	240.88	241.15
	5. 100kVAr Capacitor 1/2 Only	241.06	240.28	240.24	240.27	240.17	244.92	242.39	242.10	242.04	242.31
HV Ring Open & OLTC bottom-tap -5%	1. No Intervention	250.49	250.96	251.00	251.02	250.93	254.19	252.96	252.78	252.72	252.97
	2. LV Meshed Subs Only	248.37	250.99	251.07	251.09	251.00	250.48	253.00	252.86	252.81	253.06
	3. LV Meshed Ways Only	250.49	250.96	251.01	251.02	250.94	254.19	252.96	252.77	252.73	252.97
	4. LV Meshed Subs & Ways Only	248.41	251.02	251.09	251.10	251.02	250.49	253.02	252.88	252.84	253.08
	5. 100kVAr Capacitor 1/2 Only	254.00	252.98	252.95	252.97	252.88	257.54	255.03	254.76	254.70	254.95

Caunce Road Circuit Voltage Profiles: HV Ring Closed

Special: 6.6kV HV network from Green operated as closed rings, creates problems for protection, but solvable.



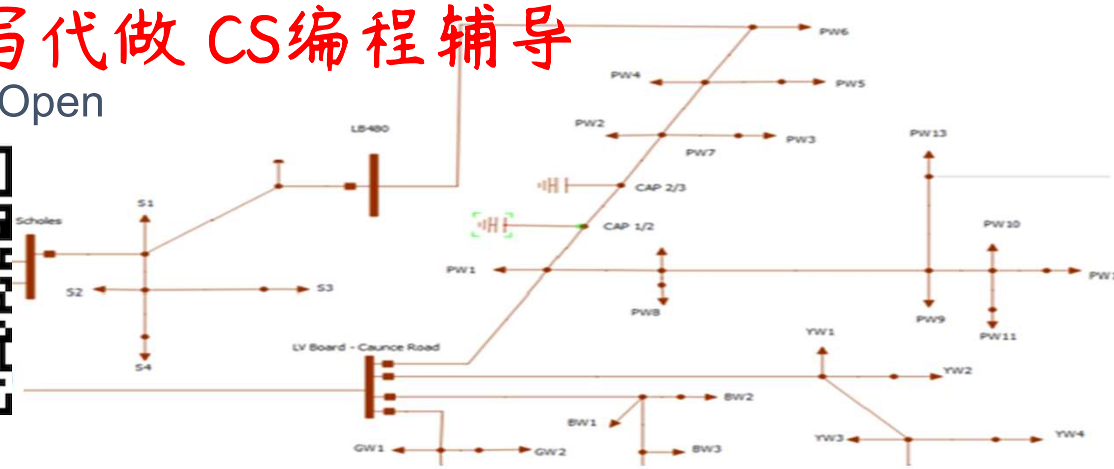
Min Demand of 0.2kW _ (2.28kW PV average installation)

Case	Scenario	Voltage Level at 0% PV Penetration: PW5	PW12	BW3	GW5	YW4	Voltage Level at 40% PV Penetration: PW5	PW12	BW3	GW5	YW4
HV Ring Closed & OLTC top-tap +5%	1. No Intervention	226.39	226.91	226.95	226.98	226.88	230.30	228.92	228.69	228.63	228.92
	2. LV Meshed Subs Only	238.62	227.98	227.86	227.89	227.79	240.81	229.97	229.62	229.56	229.84
	3. LV Meshed Ways Only	226.39	226.91	226.96	226.98	226.88	230.30	228.92	228.69	228.64	228.92
	4. LV Meshed Subs & Ways Only	238.61	227.98	227.87	227.89	227.79	240.81	229.97	229.61	229.56	229.84
	5. 100kVAr Capacitor 1/2 Only	229.23	228.54	228.50	228.53	228.43	233.11	230.56	230.26	230.19	230.48
HV Ring Closed & OLTC mid-tap 0%	1. No Intervention	237.79	238.29	238.33	238.36	238.26	241.51	240.20	240.00	239.94	240.21
	2. LV Meshed Subs Only	243.26	238.87	238.84	238.87	238.77	245.41	240.78	240.53	240.47	240.74
	3. LV Meshed Ways Only	237.79	238.29	238.33	238.35	238.26	241.51	240.20	240.00	239.95	240.21
	4. LV Meshed Subs & Ways Only	243.26	238.87	238.85	238.86	238.77	245.41	240.78	240.53	240.48	240.74
	5. 100kVAr Capacitor 1/2 Only	240.79	240.01	239.97	240.00	239.90	244.48	241.94	241.66	241.60	241.87
HV Ring Closed & OLTC bottom-tap -5%	1. No Intervention	250.39	250.86	250.90	250.92	250.83	253.92	252.69	252.50	252.45	252.70
	2. LV Meshed Subs Only	248.39	250.90	250.97	250.99	250.90	250.50	252.73	252.59	252.54	252.79
	3. LV Meshed Ways Only	250.39	250.86	250.90	250.92	250.83	253.92	252.69	252.50	252.45	252.70
	4. LV Meshed Subs & Ways Only	248.39	250.90	250.97	250.99	250.90	250.50	252.73	252.59	252.54	252.79
	5. 100kVAr Capacitor 1/2 Only	253.56	252.70	252.65	252.67	252.58	257.18	254.58	254.29	254.23	254.49
	6. 100kVAr Capacitor 2/3 Only	254.01	252.70	252.65	252.67	252.58	257.65	254.58	254.29	254.23	254.49

Caunce Road Circuit Voltage Profiles: HV Ring Open

6.6kV HV network from Green St, normally operated as open rings

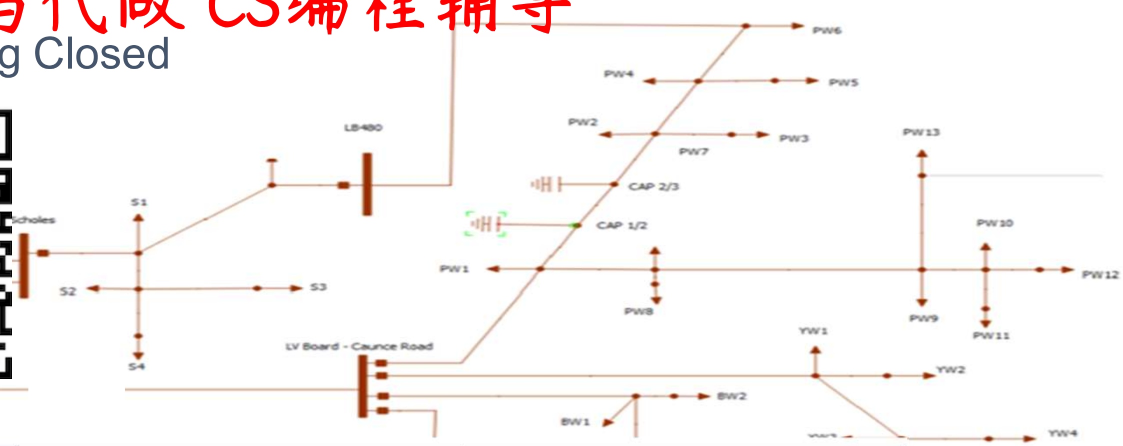
Max Demand of 1.5kW _ (2.28kW PV a



	Scenario	Voltage Level at 0% PV Penetration					Voltage Level at 40% PV Penetration				
		PW5	PW12	BW3	GW5	YW4	PW5	PW12	BW3	GW5	YW4
HV Ring Open & OLTC top-tap +5%	1. No Intervention	214.33	218.44	218.79	219.01	218.22	218.82	220.83	220.89	221.01	220.64
	2. LV Meshed Subs Only	229.28	220.04	220.19	220.41	219.62	231.60	222.39	222.29	222.41	222.04
	3. LV Meshed Ways Only	214.33	218.43	218.84	218.95	218.21	218.82	220.83	220.93	220.98	220.64
	4. LV Meshed Subs & Ways Only	229.33	220.04	220.25	220.37	219.63	231.60	222.39	222.33	222.38	222.04
	5. 100kVAr Capacitor 1/2 Only	217.28	220.15	220.44	220.65	219.87	221.75	222.58	222.56	222.68	222.31
HV Ring Open & OLTC mid-tap 0%	1. No Intervention	225.47	229.37	229.71	229.92	229.16	229.56	231.48	231.55	231.66	231.30
	2. LV Meshed Subs Only	233.93	230.06	230.28	230.49	229.74	236.25	232.14	232.12	232.24	231.88
	3. LV Meshed Ways Only	225.47	229.37	229.76	229.88	229.16	229.56	231.48	231.58	231.63	231.30
	4. LV Meshed Subs & Ways Only	233.93	230.06	230.33	230.45	229.74	236.25	232.14	232.16	232.21	231.88
	5. 100kVAr Capacitor 1/2 Only	228.41	231.05	231.30	231.51	230.76	232.45	233.13	233.13	233.25	232.88
HV Ring Open & OLTC bottom-tap -5%	1. No Intervention	238.14	241.83	242.15	242.35	241.63	242.01	243.83	243.91	244.02	243.67
	2. LV Meshed Subs Only	239.04	241.97	242.28	242.48	241.76	241.31	243.96	244.04	244.15	243.81
	3. LV Meshed Ways Only	238.14	241.83	242.20	242.31	241.63	242.01	243.83	243.94	243.99	243.67
	4. LV Meshed Subs & Ways Only	239.04	241.97	242.33	[illegible]	241.76	241.31	243.96	244.08	244.12	243.81
	5. 100kVAr Capacitor 1/2 Only	241.25	243.62	243.85	244.04	243.33	245.13	245.63	245.61	245.72	245.38

Caunce Road Circuit Voltage Profiles: HV Ring Closed

Special: 6.6kV HV network from Green St, operated as closed rings, creates problems for protection, but solvable.



Max Demand of 1.5kW _ (2.28kW PV average installation)

HV Ring Closed & OLTC top-tap +5%

PV average installation)	Voltage Level at 0% PV Penetration					Voltage Level at 40% PV Penetration				
Scenario	PW5	PW12	BW3	GW5	YW4	PW5	PW12	BW3	GW5	YW4
1. No Intervention	213.96	218.08	218.43	218.65	217.86	218.27	220.29	220.35	220.47	220.10
2. LV Meshed Subs Only	[illegible]	[illegible]	219.41	219.63	218.84	[illegible]	[illegible]	221.33	221.44	221.07
3. LV Meshed Ways Only	213.96	218.08	218.49	218.61	217.86	218.27	220.29	220.39	220.44	220.10
4. LV Meshed Subs & Ways Only	229.30	219.26	219.46	219.58	218.84	231.67	221.43	221.36	221.41	221.07
5. 100kVAr Capacitor 1/2 Only	216.75	219.66	219.93	220.15	219.36	221.04	221.88	221.86	221.98	221.61

HV Ring Closed & OLTC mid-tap 0%

Scenario	PW5	PW12	BW3	GW5	YW4	PW5	PW12	BW3	GW5	YW4
1. No Intervention	[illegible]	[illegible]	229.71	229.92	[illegible]	229.56	231.48	231.55	231.66	231.30
2. LV Meshed Subs Only	233.93	230.06	230.28	230.49	229.74	236.25	232.14	232.12	232.24	231.88
3. LV Meshed Ways Only	225.47	229.37	229.76	229.88	229.16	229.56	231.48	231.58	231.63	231.30
4. LV Meshed Subs & Ways Only	233.93	230.06	230.33	230.45	229.74	236.25	232.14	232.16	232.21	231.88
5. 100kVAr Capacitor 1/2 Only	[illegible]	[illegible]	231.30	231.51	230.76	232.45	233.13	233.13	233.25	232.88

HV Ring Closed & OLTC bottom-tap -5%

Scenario	PW5	PW12	BW3	GW5	YW4	PW5	PW12	BW3	GW5	YW4
1. No Intervention	238.14	241.83	242.15	242.35	241.63	242.01	243.83	243.91	244.02	243.67
2. LV Meshed Subs Only	239.04	241.97	242.28	242.48	241.76	241.31	243.96	244.04	244.15	243.81
3. LV Meshed Ways Only	238.14	241.83	242.20	242.31	241.63	242.01	243.83	243.94	243.99	243.67
4. LV Meshed Subs & Ways Only	[illegible]	241.97	[illegible]	242.44	241.76	241.31	243.96	244.08	244.12	243.81
5. 100kVAr Capacitor 1/2 Only	241.25	243.62	243.85	244.04	243.33	245.13	245.63	245.61	245.72	245.38

ENW Smart Street: Caunce Road

- Addition of 100kVAr capacit[illegible] down PW feeder shows increase of around 3 - 3.5 V at the PW5 end node [illegible] on transformer tap position (the higher the tap position, the lower the volta[illegible]).
  - A further increase of up to 1 v[illegible]ined by moving the capacitor to two thirds of the way down the LV feeder (again depending on the tap position).
- Results show the midpoint 150kVAr and 200kVAr capacitors produce a voltage rise of around 4.5 to 5 volts and 5.5 to 6 volts respectively.
  - Again, a further increase of up to 1 volt can be gained by moving the capacitor to two thirds of the way down the feeder.
- Total circuit losses are greater when the capacitor is placed 2/3 down the feeder rather than at the midpoint.
- Comparing the voltage profiles and the voltage losses in the results tables in Appendix B, a 100kVAr capacitor positioned halfway down the PW feeder appears to be the optimum scenario.
  - This is considering that the end node voltage will only see an additional 1 volt rise when installing a 150kVAr capacitor in the same position. .

ENW Smart Street Roll-out

- In 2019, Ofgem awarded ENW £18 e roll-out of Smart Street technology.
- ENW are now rolling-out the techno ribution substations across their network, targeting areas with a high uptake of low carbon technolog
- ENW state "benefit 45,000 custome ctricity consumption by 5-8% per year".
- ENW state "in the longer term, this roll-out will save 143,860 tonnes of carbon out to 2050 – this is the equivalent of removing 2,570 cars from our roads every year."

[Smart street library (enwl.co.uk)](https://www.enwl.co.uk)

- *Attempted to summarise how ENW is adding automation into its HV and LV network to reduce operating costs and losses and to provide real benefits to consumers.*
- *ENW results indicate 1% voltage drop delivers about 1% energy saving to a consumer, consequently if ENW can deliver voltage reductions to a typical customer of 5%, whilst ensuring supply voltage remains above 0.94pu = 216V, then 5% energy saving appears realistic.*

- *If you assume all your domestic loads are resistors (without thermostat or time control) the power dissipated is V^2/R, where R is the total resistance of all your switched-on appliances in parallel*
- *Hence, if your resistive load for the next hour is 10Ω, at 230V you will consume 5.3kWh, at 254V it will increase to 6.5kWh (21% rise) and at 216V it will reduce to 4.7kWh (12% fall).*

Note: Many domestic loads are constant power, i.e. as you lower the voltage the current increases and generally losses increase, others are thermostatically controlled i.e. once they reach temperature they turn off. This is why "average" energy use increases approximately linearly with voltage.

Q & A

- Hopefully this lecture raise[illegible]estions and illustrated the advantages and disadvantages of integrati[illegible]ms into the physical systems associated with an HV and LV network.

- Aspects of Smart Street and numerous other Ofgem supported distribution network innovation projects have started to roll-out onto real HV and LV networks.

- What this means for the reliability and resilience of the Grid is still an unknown, but expect in the near future issues of cyber security will become an important discussion issue for DNO’s and the government.