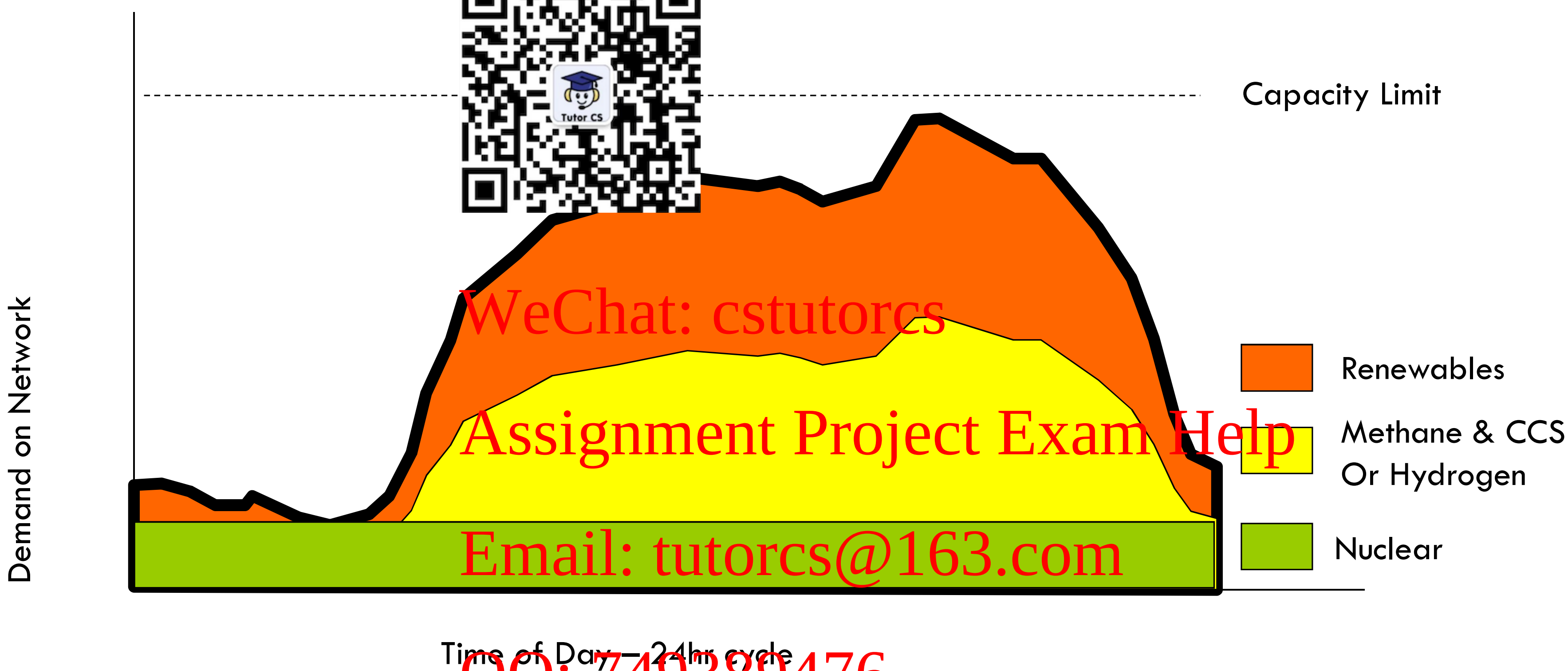
University of Exeter
Centre for Smart Grid

L2: Smart G
Sustainable Energy Systems

Impact of Low Carbon Technologies on Distribution Networks

Prof Peter Crossley

If this is a "typical" regional 24 hour working-day load profile. How can we use renewables in the future?



Is this the shape of a our future energy demand and if yes how do we ensure renewables, clean coal and nuclear deliver the energy when we require it

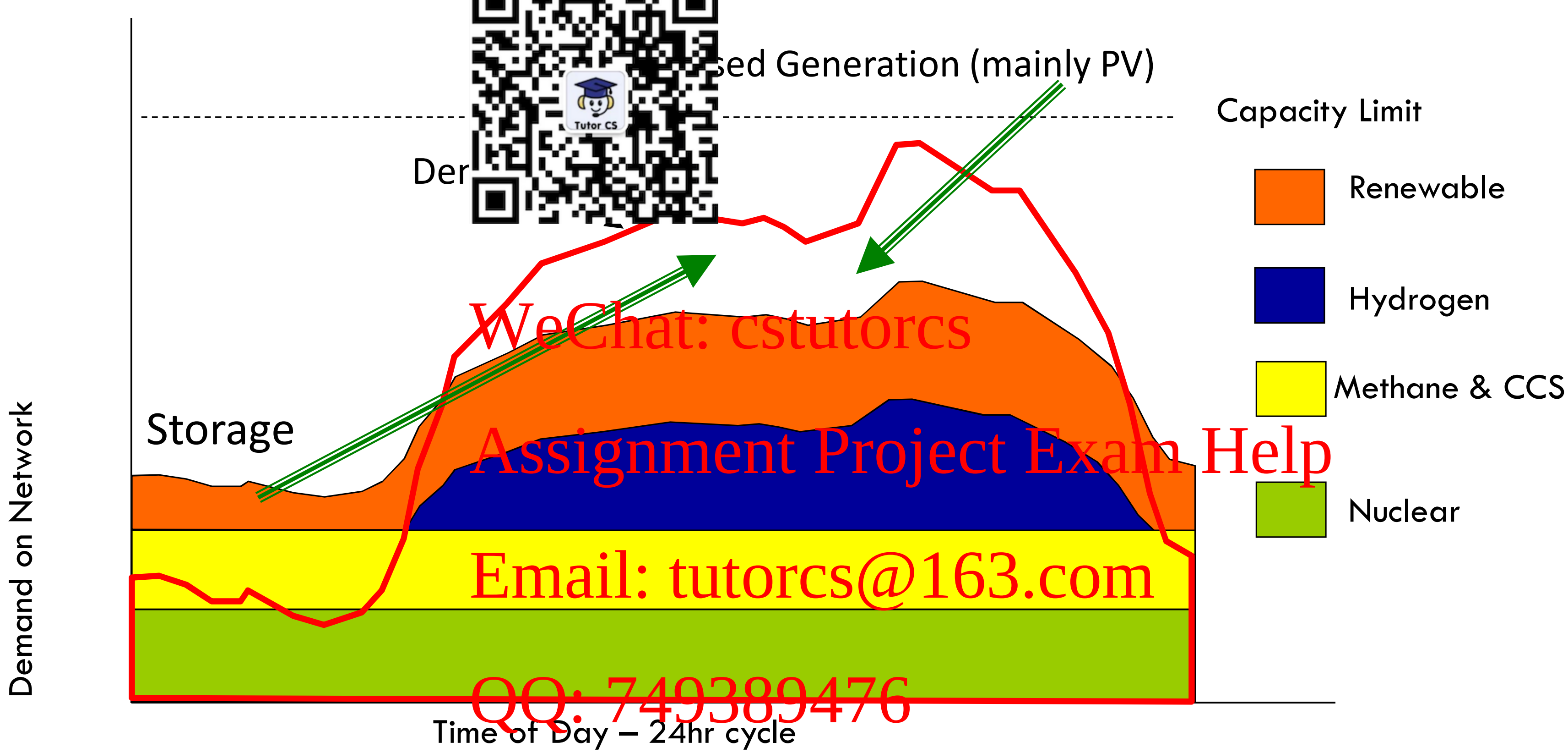
What if renewables generate at wrong times?

Can renewables generate overnight and store the energy?

Can storage then deliver the energy at peak times?

Is this economically viable?

How do we ensure the lights stay on in 2030 or 2040?



Can renewables, coal and gas with carbon capture & storage, nuclear, green hydrogen, storage & dispersed "clean" generation deliver the energy when we require it at a cost we can afford ?

Traditional Power System

UK Electricity Market Structure

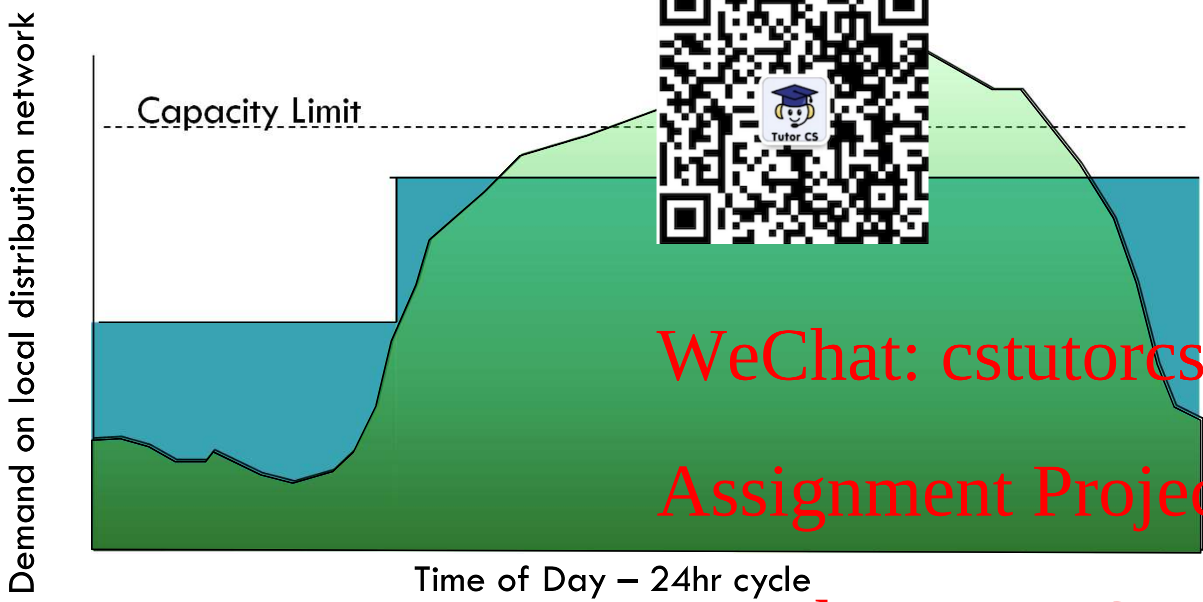
How can your local network cope ?

What if demar[illegible]es above local network capacity?

Does local refer[illegible]city, town or the supply to your house?

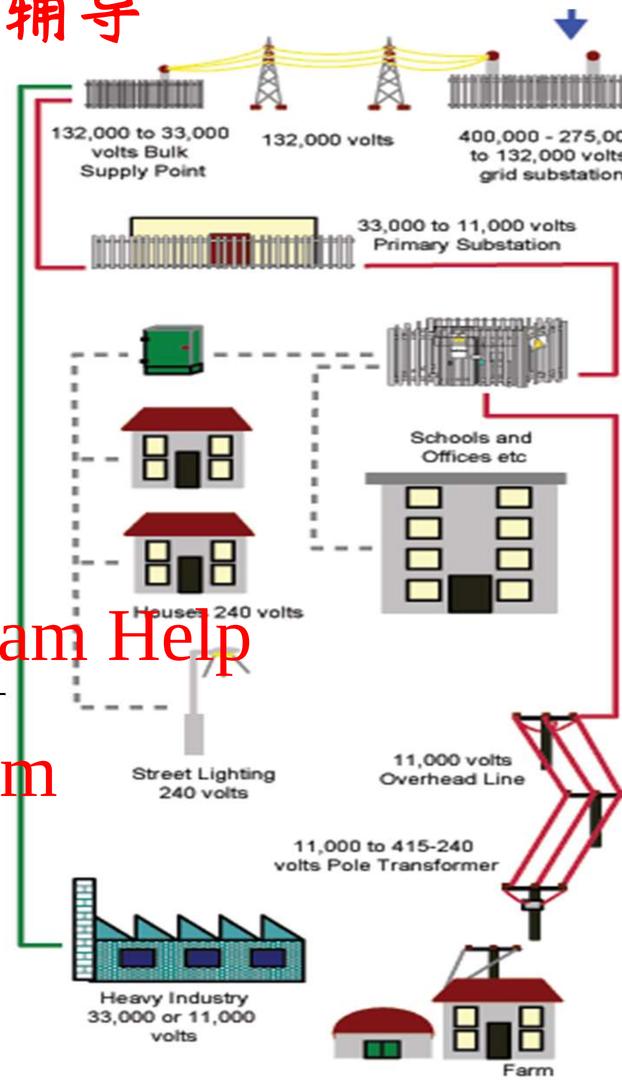
UK:- expect significant demand growth due to EVs (depends on gasoline prices & CO2 legislation) & domestic electric heating (depends on natural gas prices and government policies)

Dynamic Demand, Storage & DG lowers demand below feeder/network capacity limit.



Future Demand with load shifting (demand response)

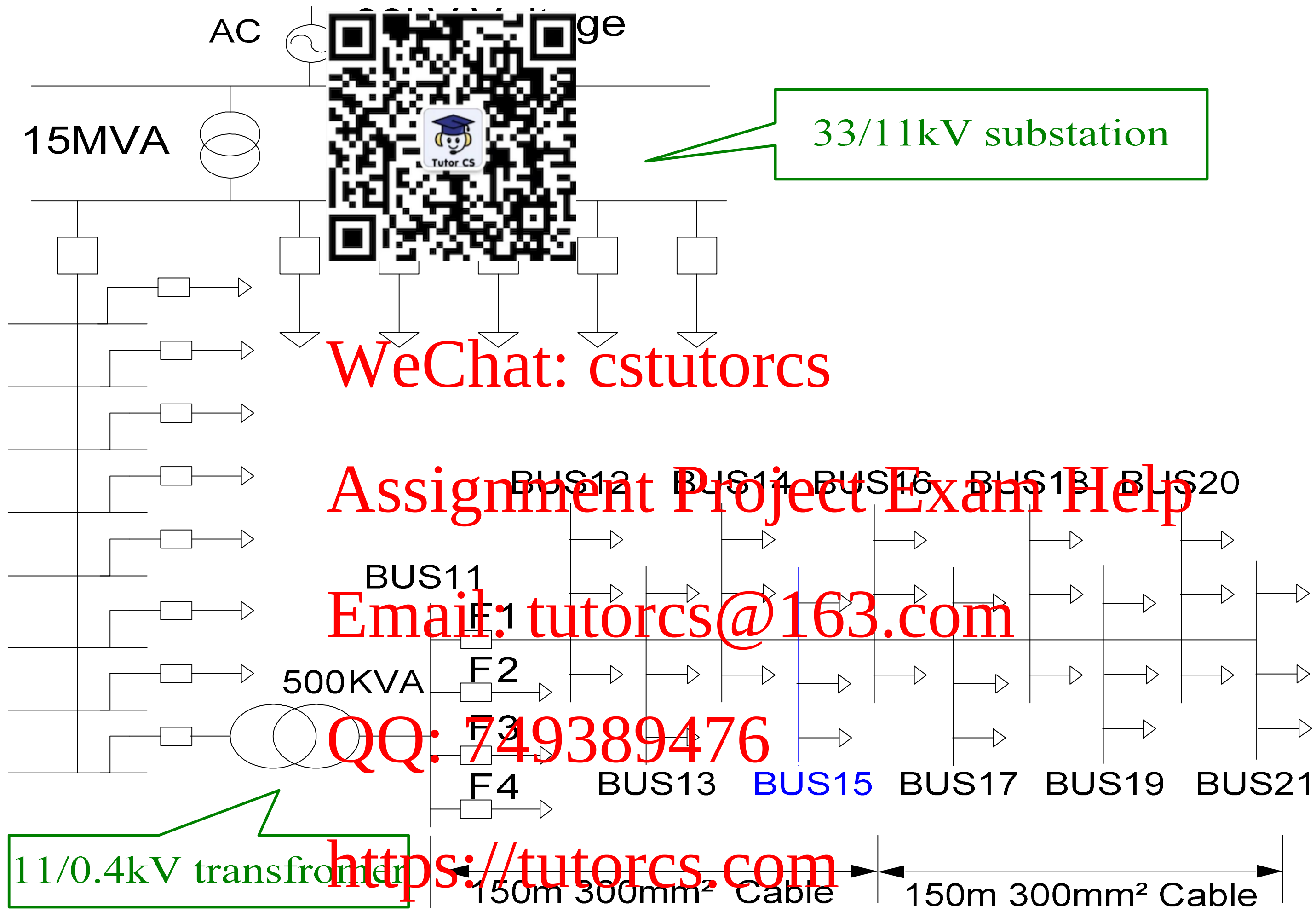
Future Demand without load shifting



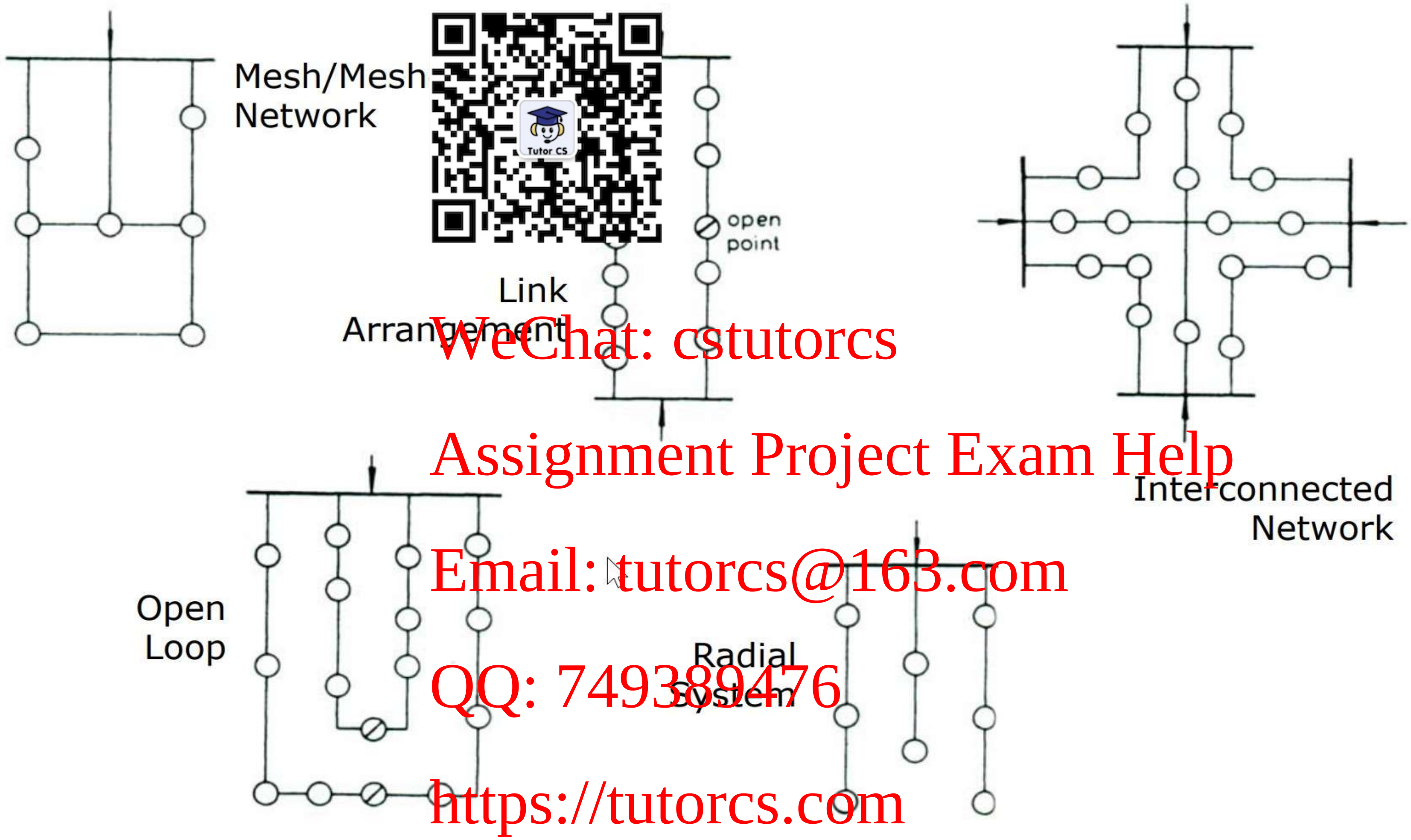
Can we shift demand from peaks to troughs?

or can we match demand to availability of low cost, low carbon energy & capacity of network

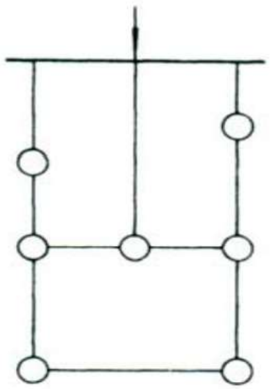
Typical UK urban distribution network



Distribution Network Configurations

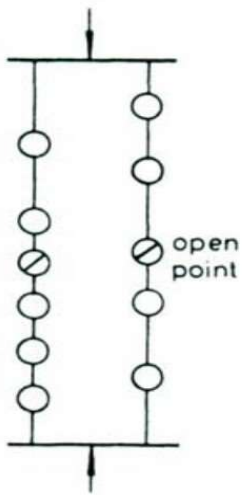


Distribution Network Configurations



Mesh/N
Netwo

- More reliable
- Higher voltages
- More lines, protection scheme more complex, more cost
- Lower asset utilisation



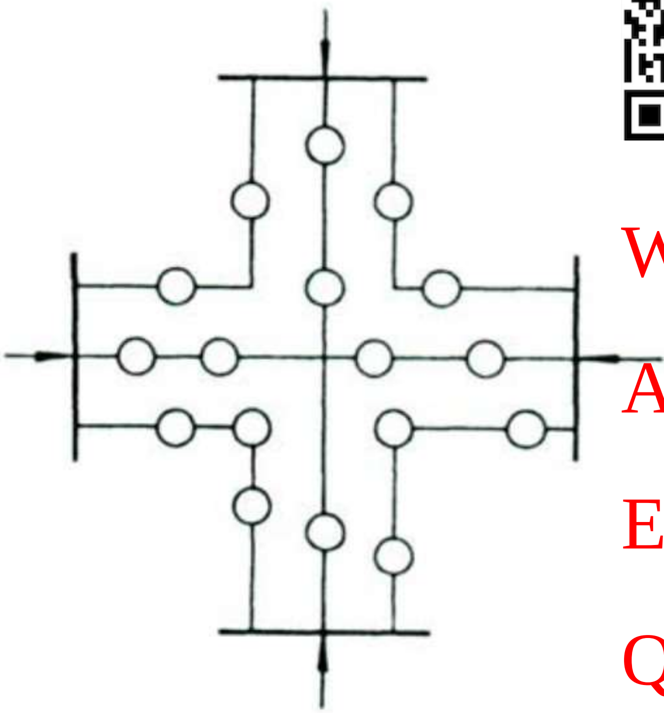
Link Arrangement

- More reliable, two in-feeds
- Less assets (than previous)
- Better asset utilisation (than previous)
- Simplicity (topology, protection)
- Less expensive

Distribution Network Configurations

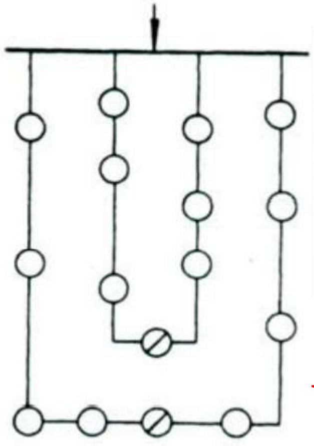
nnected

k



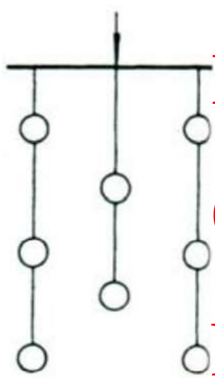
- Very high reliability
- Very expensive
- Low asset utilisation
- Complex protection, voltage regulation

Distribution Network Configurations



Open Loop

- Less reliable
- Simple protection
- Cheaper

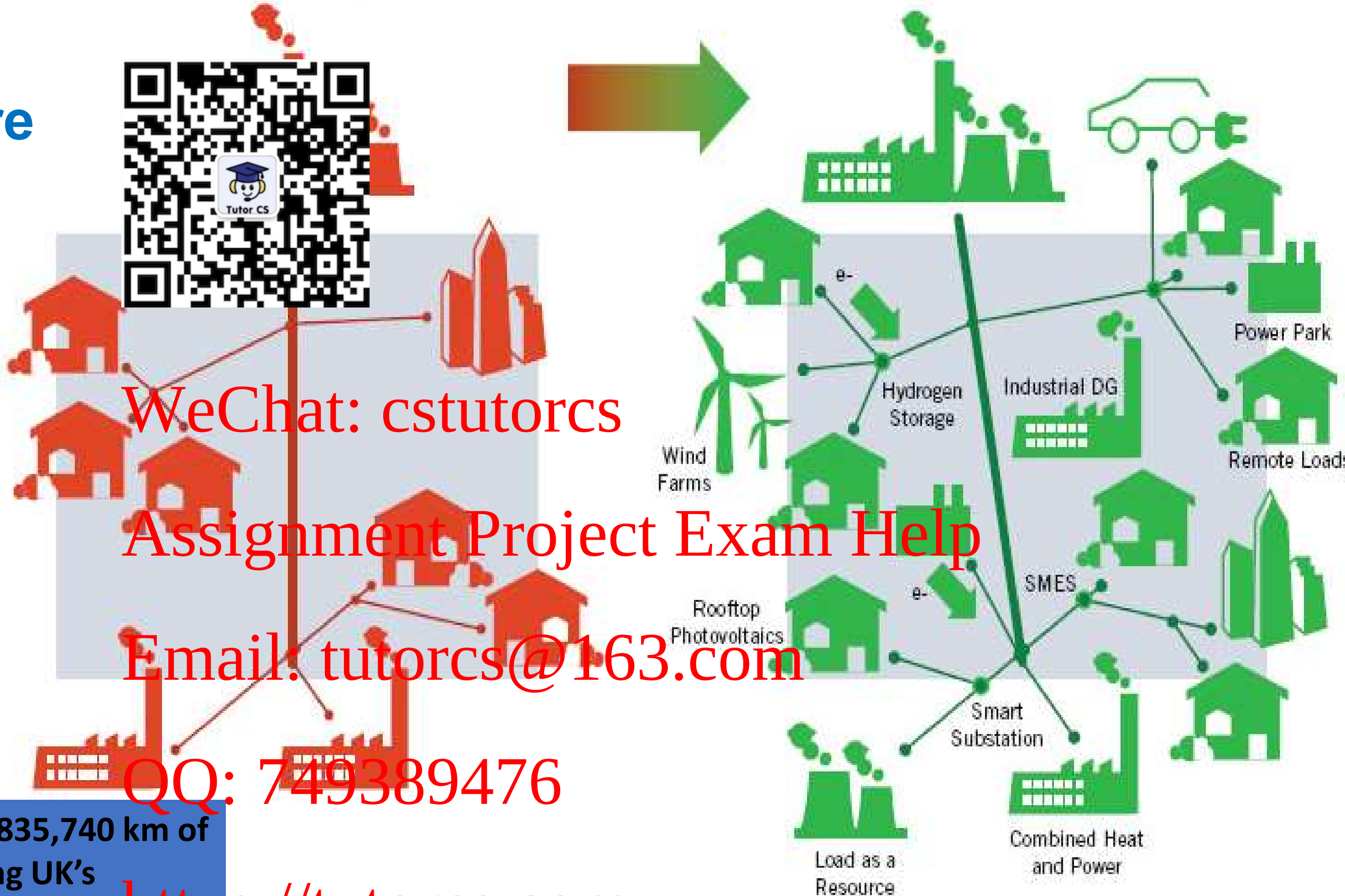


Radial System

- Cheapest
- Least reliable
- Simplest

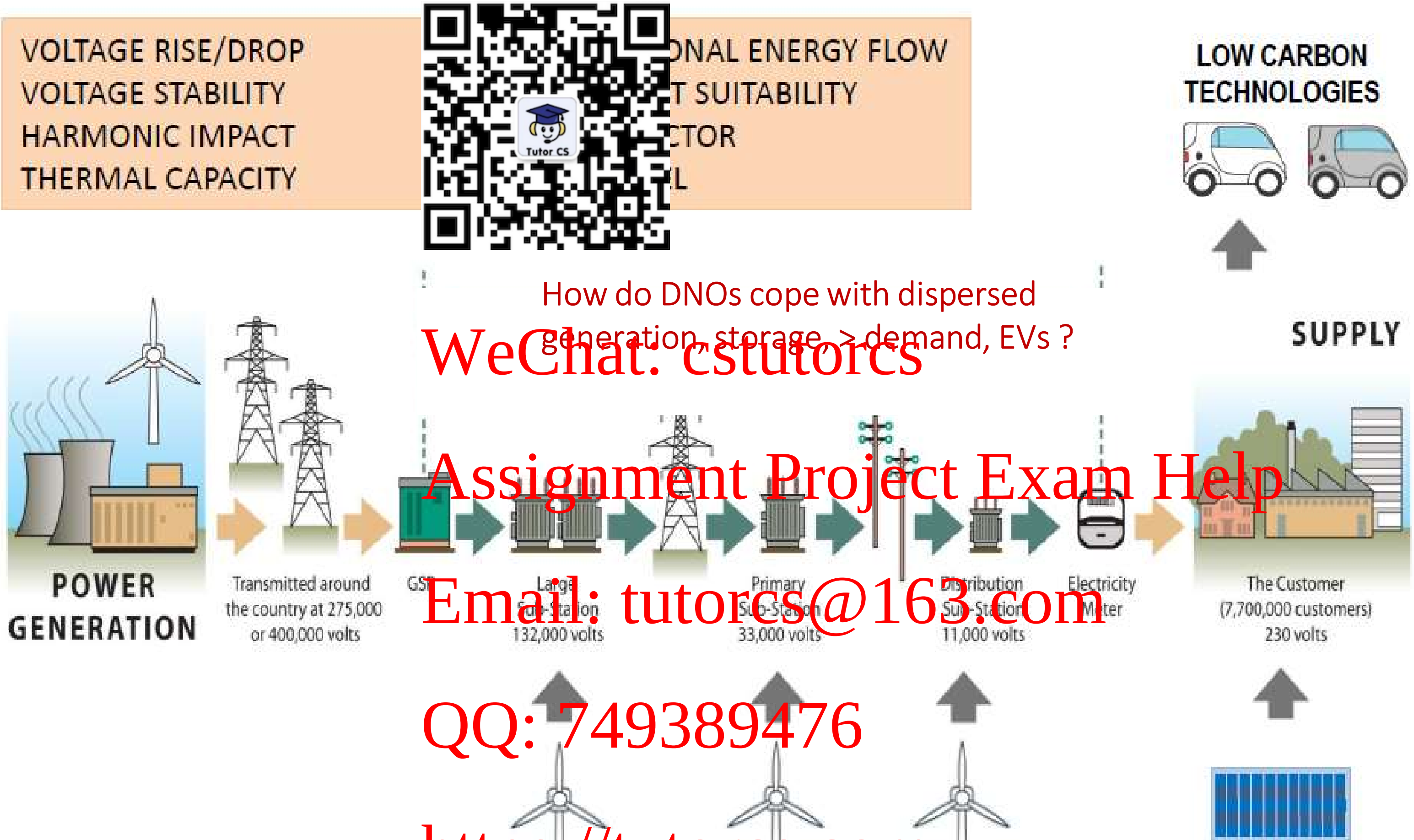
Topology of Urban LV Networks

Evolution to future distribution grid



UK transports electricity along 835,740 km of lines and cable. Cost of replacing UK's distribution network is £95.6 billion

WPD Evolution to future distribution grid



Ofgem encouraged DNOs to innovate by investing in trials; costs are recovered via network price controls.

Electricity Network Innovation in UK

- UK electricity networks (DNO's) are [illegible]allenges of decarbonisation
  - concern is speed of change
- Expect to deliver energy security a[illegible] in a low carbon economy
  - concern, kWh carbon intensity in 2030 or 2040?
  - Government states this needs to be <70gCO_2/kWh by 2030, but Committee for Climate Change wants 50gCO_2/kWh
    - What will the UK achieve?
- Since DNO's and the TSO are natural monopolies, Government and Ofgem's framework for regulating the DNO's is critical in ensuring Net-Zero is achieved
  - concern, will Government and Ofgem stick to its timetable for Net-Zero.

Ofgem LCNF Tier-1 smart-grid projects (operated 2010 – 2015)

Tier-1 projects allowed DNOs [illegible]oportion of expenditure incurred on small projects.

Tier-1 projects had to trial a:

- specific piece of new (unprove[illegible]uipment with direct impact on Distribution System
- novel application of existing Distribution System equipment
- new operational practice for Distribution System
- novel commercial arrangement with a Distribution System User

Tier-1 projects had to demonstrate they:

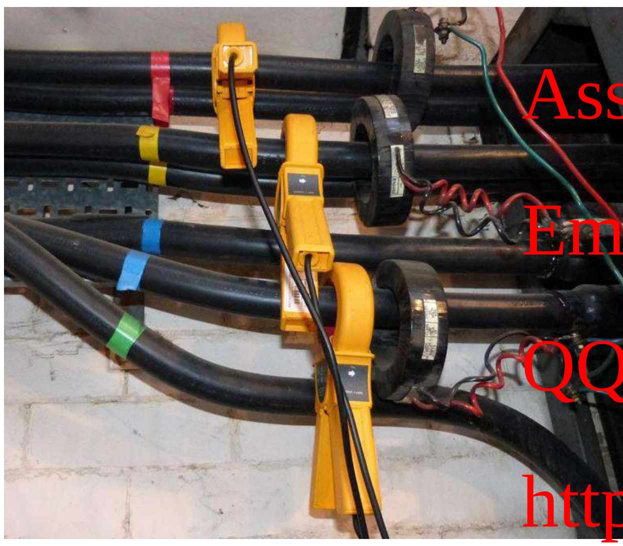
- accelerate development of low carbon energy sector and provide net financial benefit to customers
- have direct impact on DNO's Distribution System
- generate new knowledge that can be shared amongst all DNOs
- focus on network methods that are at the trial stage
- do not lead to unnecessary duplication with other projects

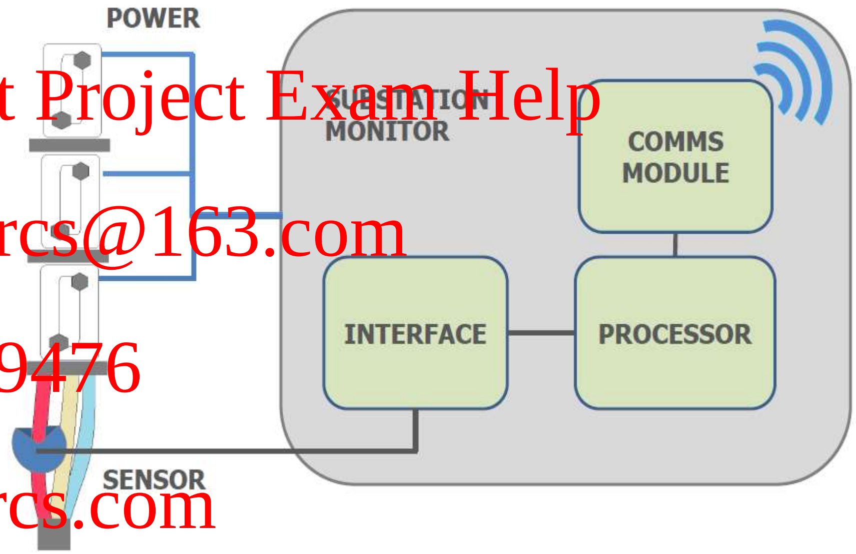
Electricity North West Tier-1 Projects:

- **'Bidoyng' Smart Fuse:**
  - install "Smart Fuses" on th (LV) network and determine if they are able to reduce the impact of transient faults.
- **Voltage Management on L Busbars:**
  - deploy and assess range of voltage management technologies and techniques across 15 distribution substations.
- **Low Voltage Network Solutions:**
  - deploy monitoring equipment to provide greater understanding of the operating characteristics and demands of LV networks.
- **Low Voltage Integrated Automation:**
  - new integrated solution for voltage control of LV networks.
- **Low Voltage Protection And Communications:**
  - develop & implement advanced protection & communications to meet the requirements of future LV networks.
- **Fault Current Active Management:**
  - methods other than network reinforcement to reduce fault levels.

ENW Tier-1: **Low Voltage Network Solutions:**

- **Project will deploy measurement [illegible] recording equipment to help ENW understand operating and demand characteristics of LV netw[illegible]**
- **University of Manchester helped [illegible] meaningful sample of representative LV network feeders.**
- **Activities:**
  - measurement and data collec[illegible]
  - network modelling
  - developing appropriate LV network solutions
  - validating conclusions of other LCNF LV trials on ENW network





'Bidoyng' Smart Fuses

The unit fits into existing LV … l is based upon the patented concept of two LV fuses in parallel, creating a robust si… …ser.

There are two fuses in the device, a primary and a secondary fuse. The primary carries the load current until a fault causes it to blow. Then after a pre-programmed delay the secondary fuse is switched into circuit and the network is re-energised.

Incorporating extensive communications and intelligence, the **BIDOYNG** enables the development of a real 'Smart' Grid for the distribution network. The modern utility can now create a more efficient, low carbon network while also significantly improving performance.

Fuse replacements can be scheduled and embedded fault location means the cost of finding and repairing intermittent faults is considerably reduced.

Wide Area Data Monitoring

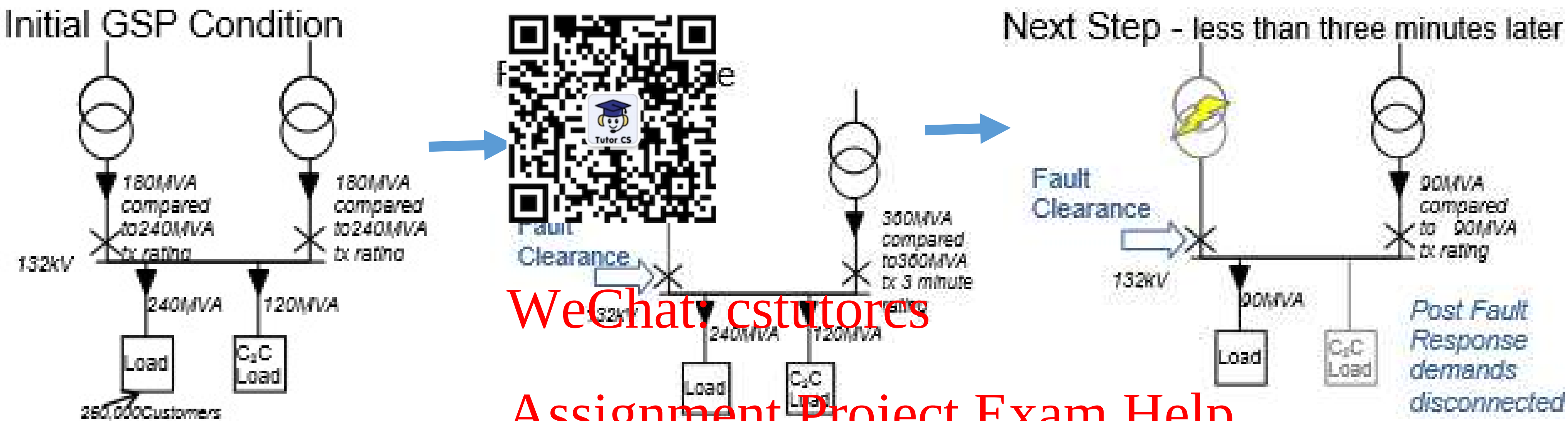
Wide Area Data Gathering	Amperion, Manchester University	A Power Line Carrier system was successfully trailed on our OHL network in Cumbria	No financial benefits were delivered by this trial but we gained valuable information and knowledge regarding the performance of modern PLC systems	This system was only used in a trial configuration and was used only to transmit test data, the system could be used operationally where other communications platforms (PMR, GSM) were unsuitable

ENW Capacity to Customers (C_2C) Demo Project: 2012 - 2015

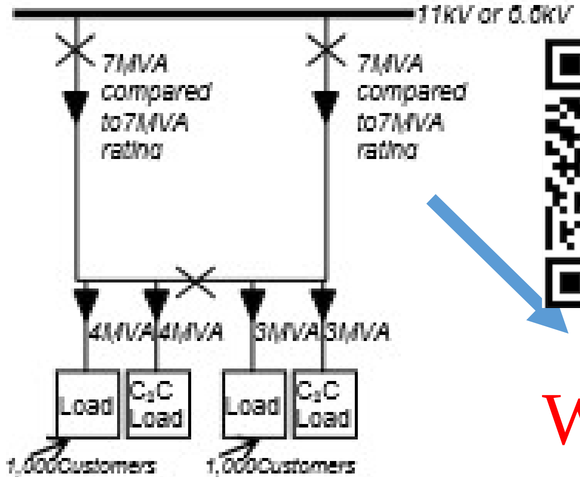
- Electricity North Wes[illegible] £10M to develop C_2C, aims to:
  - release untapped [illegible] network capacity
  - customers savings [illegible]ing how electricity is used
  - prevents infrastructure improvement costs being passed to customers

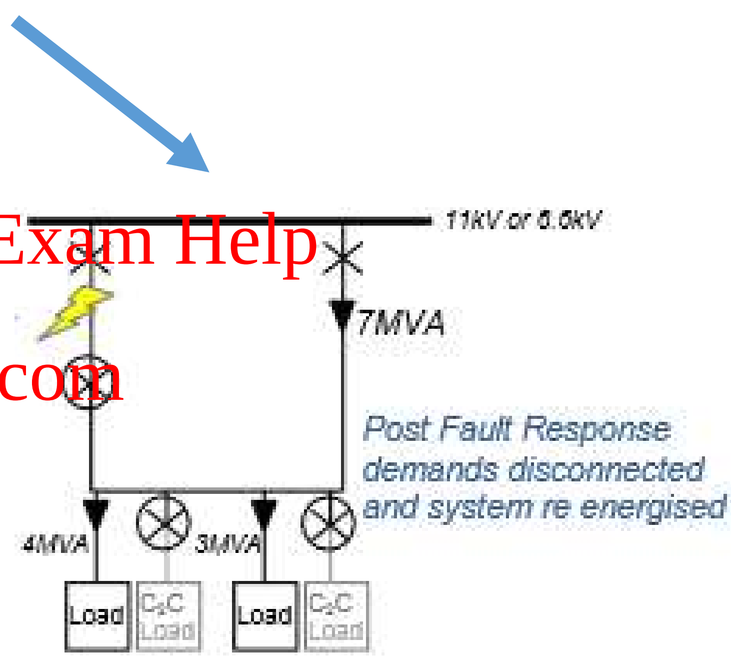
- How ENW will increase capacity:
  - network operator must plan for the future and invest customers money into the region's electricity network.
  - trial smart-grid technology to reduce need for investment
  - C_2C provides more power using existing assets. It could deliver the extra capacity without expanding the network.

ENW Capacity to Customers (C_2C)



C_2C = Reconfiguring the network





Main findings are:

C2C releases extra capacity and delivers economic and carbon benefits

Project demonstrated C2C can unlock real benefits for customers such as quicker new network connections at lower cost and cheaper distribution use of system costs.

Our industrial and commercial customers are willing to sign up to C2C contracts

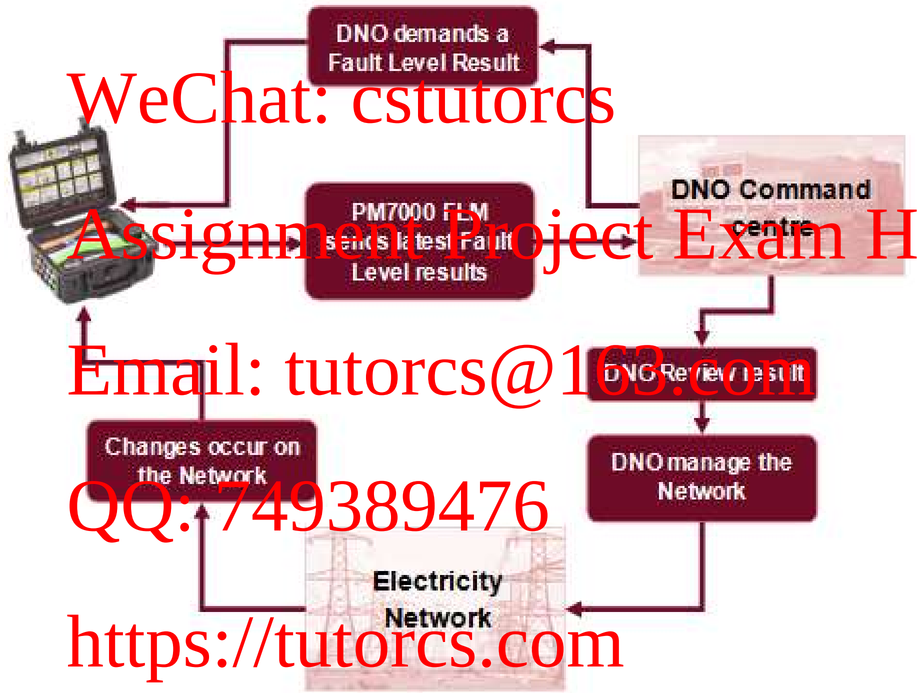
Customers offered a monthly payment or a reduced new connection charge in exchange for allowing us to manage their connection in the event of a fault. During the project we signed up ten existing customers and ten new connection agreements.

UK Government “smart-grid” policies

- UK Department of Business, Energ[illegible]trategy (BEIS) is developing the strategic, regulatory and policy frameworks to ensure “UK’s electri[illegible]iciently deliver secure & clean energy that meets UK’s energy security and climate goals”
  - In recognition of this, Of[illegible] a new innovation funding streams, beginning with the Low Carbon Network Fund (L[illegible]city distribution projects in 2010.
  - In 2015, this was replaced by Network Innovation Competition (NIC) and Network Innovation Allowances (NIA) under the RIIO-ED1 price control (Revenue = Incentives + Innovation + Outcomes) regime.
  - RIIO-ED1 will end in 2023, and will be replaced with RIIO-ED2.
    - RIIO-ED2 price control sets the outputs the 14 electricity Distribution Network Operators (DNOs) need to deliver for their consumers and the revenues they are allowed to collect from 1 April 2023 to 31 March 2028.
  - Success of LCNF and RIIO-ED1 enabled DNO’s to create projects, demonstrating new technologies and working practices that are now being adopted as business-as-usual by companies to deliver savings for customers.

FlexDGrid: Advanced Fault Level Management

- Western Power Distribution (W… d £13.5M from UK energy regulator to revolutionise the power network in Birmingh…
- WPD will use new solutions to… ate more local generation.
  - connection of generation t… works increases fault level



FlexDGrid: Advanced Fault Level Management

Connection of generation directly to u… etworks can increase the fault level.

FlexDGrid will investigate:

- Enhancing simulation processes … predict short-circuit currents.
- Monitoring the network in a gre… il.
- Installing new technologies that … v of short-circuit currents when faults occur in the electricity network.

Following a procurement exercise the Fault Level Measurement (FLM) device selected was built by S&C Electric. The device was based on the one installed under the WPD Tier-1 project with changes to add additional monitoring and communications.

This project ended in Mar 2017 and is now closed.

FlexDGrid: Advanced Fault Management (Birmingham)

Duration	Dec 2012 - Mar 2017
Region	West Midlands.

EXPE

£15,

FlexDGrid offered improved solution to the problem of cost-effective integration of customers' generation and demand within urban Voltage (HV) electricity networks.

ct sought to explore benefits arising from trials of complimentary Methods: a) Enhanced Fault Level Assessment; (Beta) Real-time Management ult Level; & (Gamma) Fault Level Mitigation Technologies.

Outcomes for Method Alpha were:

- detailed 11kV network models of 15 primary substations and an automated procedure for updating or developing further network models for Fault Level assessments.
- user-friendly Excel-based tool for use in primary system design for Fault Level assessments of HV networks of primary substations where FCLs have been installed.

Outcomes for Method Beta were:

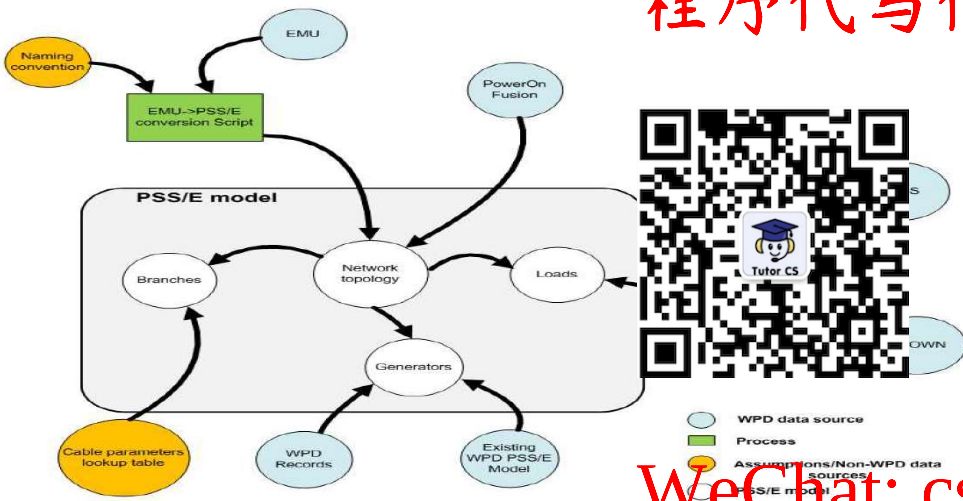
- FLMs allowed Make & Break Fault Level values to be assessed, enabling networks to operate based on these values, increasing network security & facilitating new customer connections.
- Fault Level data was fed back into models, allowing updates to planning Fault Levels.
- policy documents were developed to assist with connection & operation of FLMs.

Outcomes for Method Gamma :

- PSCFCL (Pre-Saturated Core Fault Current Limiter) installed at Castle Bromwich 132/11kV Substation
- RSFCL (Resistive Superconducting Fault Current Limiter) installed at Chester Street 132/11kV Substation
- RSFCL at Bournville 132/11kV Primary Substation

The FLEXGRID Solution can potentially deliver £1Bn savings across GB through the avoidance of network reinforcement and safeguarding of electricity network assets. This could facilitate 6 GW of generation connections and offset 5.05 MtCO2 / year.

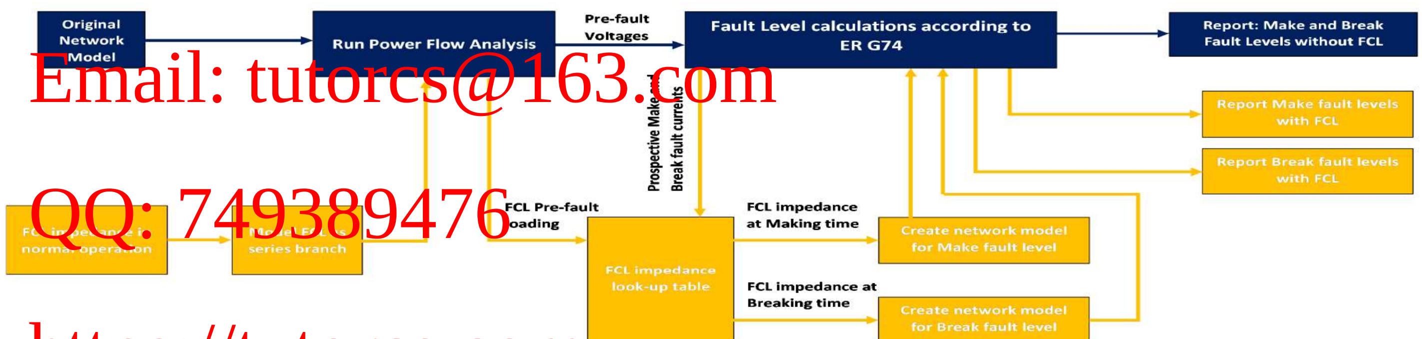
WESTERN POWER DISTRIBUTION FLEXDGRID **Closedown Report June 2017**



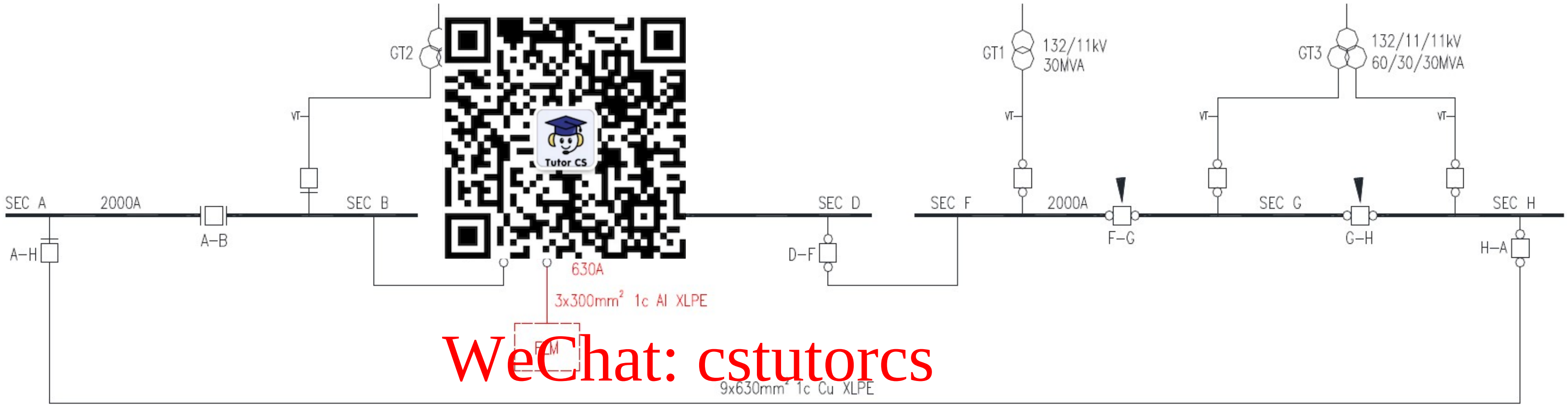
The following work was carried out:

- A sample PSS/E model of a network, representing part of Birmingham's 11kV network, was considered;
- The parameters of the sample model were varied within the range given in Table 6-3 within an assumed time to create different operation condition scenarios; and
- The corresponding Fault Levels of each scenario were calculated. The results were then compared with calculated Fault Levels from the original model to understand the impact of the each network parameter on the network Fault Level.

Parameter	Variation range
Generation power factor (PF)	Unity, 0.95 leading, 0.95 lagging, Voltage control mode (Vset = 1 pu)
Tap position at Primary Substation	Voltage at 11 kV busbar changes between 0.95 per unit to 1.03 per unit
Demand	- 10% to + 10%
General load fault in-feed	0 to 2 MVA per MVA of load



Single line diagram of connection at Elmdon:



- 11kV network in Birmingham is supplied from number of 132/11kV substations at strategic locations in and around the city.
- Direct transformation from 132kV to 11kV results in lower network impedances due to absence of an intermediate voltage supply level (such as 33kV).
- Lower network impedance resulted in very high Fault Levels on the 11kV network.
- Operation of the network with Fault Levels exceeding equipment ratings cannot be permitted as the equipment may not be able to sustain / interrupt the resultant current.
- Hence, most 11kV busbars at primary substations have to be run in split configuration.
- Operating the network in split configuration requires manual or automated sequence switching to quickly restore customers in the event of an upstream fault.

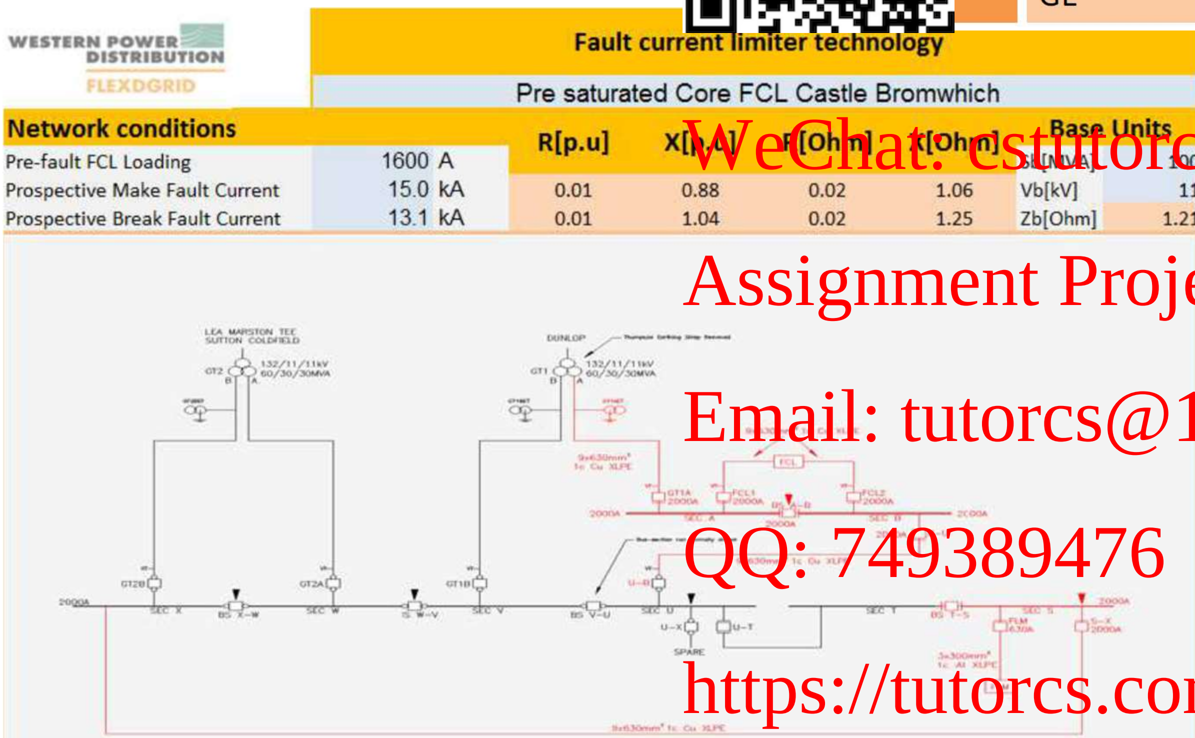
Why not build primary substations using 132/11kV transformers with higher leakage reactance?

Single line diagram of connection at Elmdon:

- Method Gamma aimed to reduce netw[illegible] through the installation of Fault Level Mitigation Technologies (FLMTs), otherwise known as Fault Cu[illegible]Ls).
- Design and installation of FCLs builds c[illegible]echnologies developed from earlier Innovation Funding Incentive (IFI), Energy Technologies Institute (ET[illegible]n Networks Fund (LCNF) projects to create a system-level approach.
- Method involved installing FCLs at five 132/11kV substations in and around the centre of Birmingham to reduce the Fault Level of the surrounding 11kV networks.
- Three different FCL technologies were chosen to be developed however; this was reduced to two following issues with the GE Power Electronic technology.
- Implementation of Method Gamma allowed the 11kV busbars at a primary substation to be connected in parallel by reducing the prospective fault infeed by connecting an FCL across the bus-section or in series with the incoming feeder.
- Objective for Method Gamma was that the chosen primary substation shall be able to accommodate additional generation, up to 10% of the firm capacity of that primary substation, without exceeding the equipment ratings following installation of an FCL.

FlexDGrid: Advanced Fault Level Management

Substation	Manufacturer	Name	Technology
Kitts Green	GE	Active Fault De-Coupler	Power Electronic
[illegible]	GridON	PSCFCL	Pre-Saturated Core
[illegible]	Nexans	SFCL+	Resistive Superconducting
[illegible]	Nexans	SFCL+	Resistive Superconducting
[illegible]	GE	Active Fault De-Coupler	Power Electronic



Castle Bromwich Fault Current Limiter, during installation

Fault level estimation - Generation Connection

Primary Substation Name	Chester Street	
Connection point / Site Number	VENTNOR AVE.	724142
Voltage [kV]	11	

		Make [kA]	Break [kA]
Switchgear ratings	@	32.8	11.4
	@	33.4	13.1

		Make [kA]	Break [kA]
Fault levels before connection	@	21.4	7.8
	@	20.49	10.44

	R [ohm]	X [ohm]
Equivalent impedance from VENTNOR AVE. to CHESTER STREET primar	0.209	0.118

Generator	Generator rating [MVA]	3.0
	Transient reactance [p.u]	0.22
	Sub-transient reactance [p.u]	0.19
	Transient reactance [ohm]	8.9
	Sub-transient reactance [ohm]	7.7

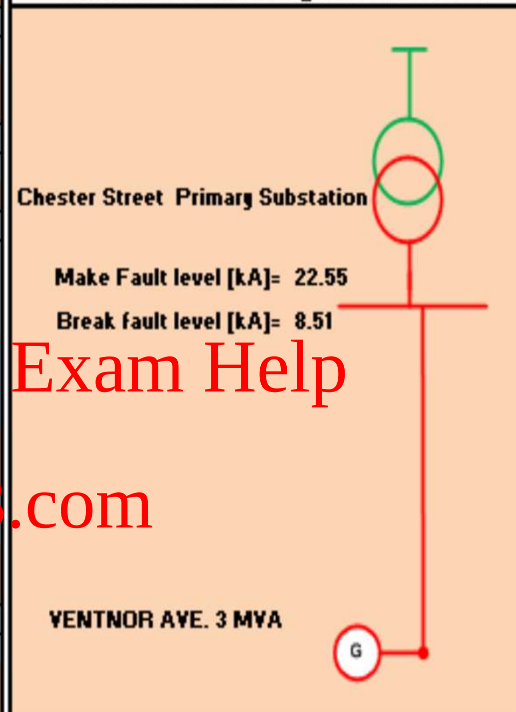
		Make [kA]	Break [kA]
Generation fault current contribution	@ Chester Street	1.15	0.71
	@ VENTNOR AVE.	1.17	0.83

		Make [kA]	Break [kA]
Fault level after connection	@ Chester Street	22.55	8.51
	@ VENTNOR AVE.	21.67	11.26

Issued by	Name
Date	02 March 201[illegible]

Base Units	
Base power [MVA]	100
Base voltage [kV]	11
Base current [kA]	5.25
Base impedance [Ohm]	1.21

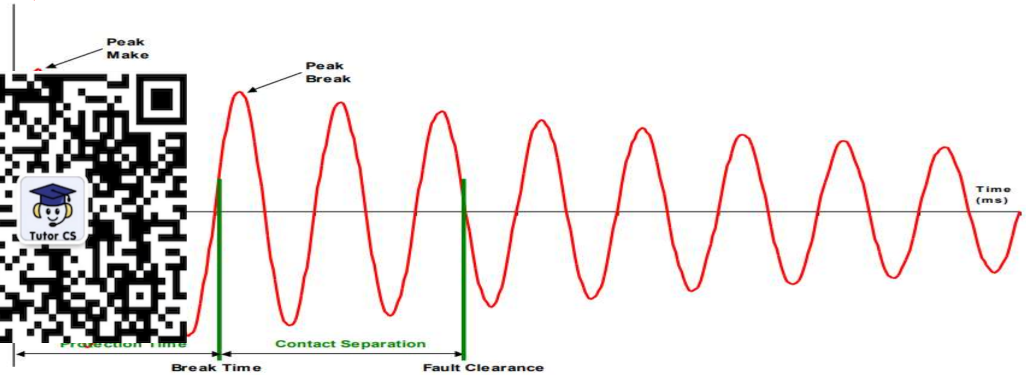
Generation connection @ VENTNOR AVE.



Email the results (*.pdf)

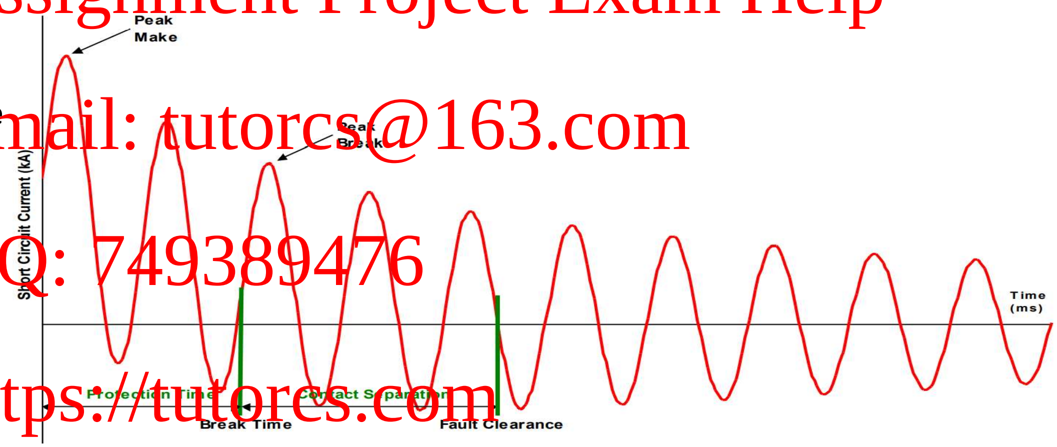
What happens when a short-circuit fault occurs on the 11kV busbar?

Synchronous generators deliver an AC component of fault current that reduces from very-high "sub-transient" value to a high "transient" value to a lower "steady state" value, as shown:



It also delivers a DC component, which is actually an exponential defined by X/R, it can start with a magnitude equal to the peak value of the AC sub-transient current, as shown:

If you add the AC & DC components together, you have an offset fault current with a "peak-make" value that is 2 – 3x the "peak-break" value



Fault levels before connection

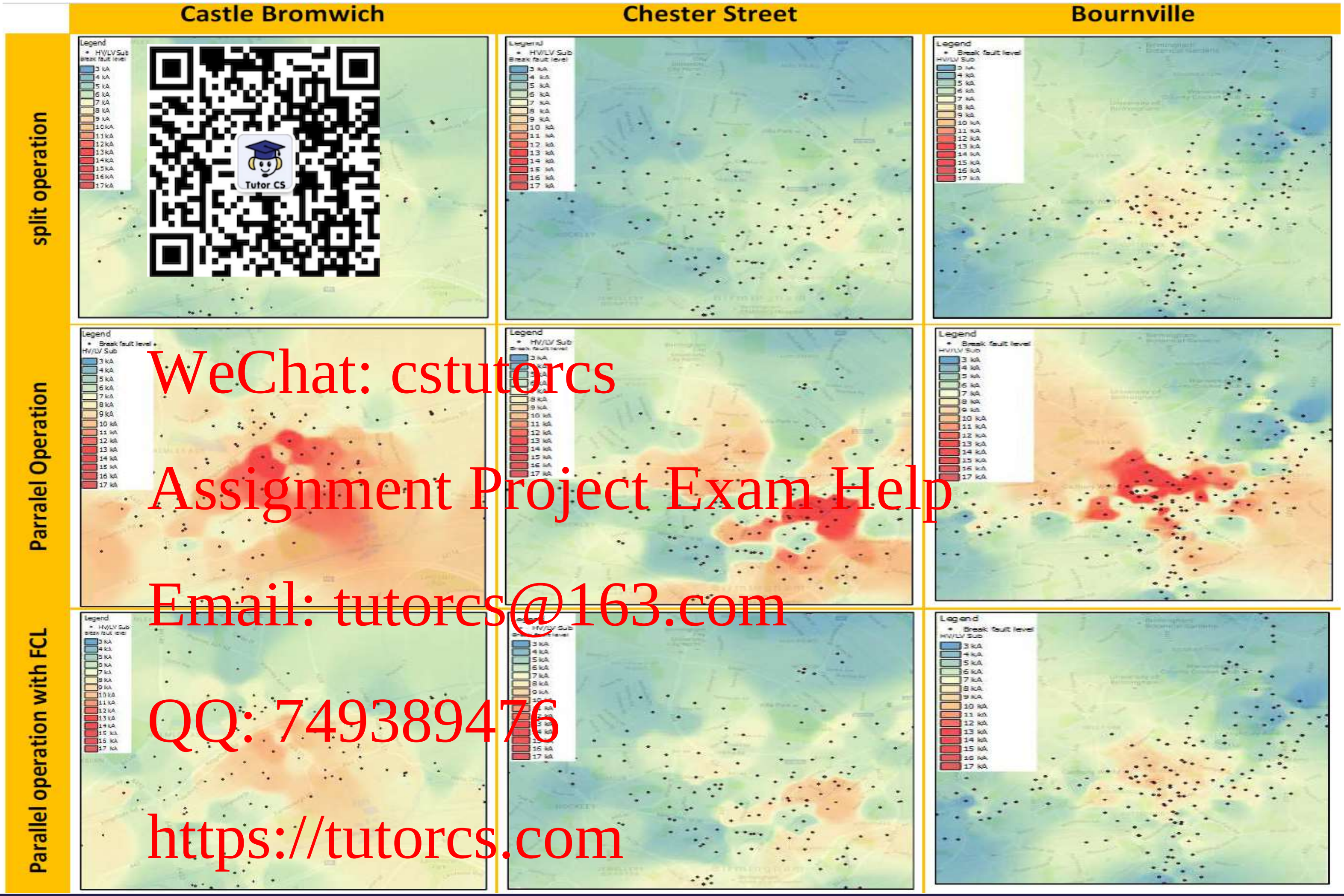
	Make [kA]	Break [kA]
@ Chester Street	21.4	7.8
@ VENTNOR AVE.	20.49	10.44

Generation fault current contribution

	Make [kA]	Break [kA]
@ Chester Street	1.15	0.71
@ VENTNOR AVE.	1.17	0.83

Heat maps demonstrate effect of FCLs on Fault Levels at/near Castle Bromwich, Chester Street & Bournville Primary Substations

Three network arrangements are considered:



FlexDGrid: Fault Level Management using Fault Current Limiters

- Fault Current Limiters (FCL) allow the 11kV [illegible] operate in parallel (i.e. multiple 132/11kV transformers) and distributed generators supply each 11 [illegible]
- Improves reliability & reduces custom[illegible]e. single 132/11kV transformer can trip, without disconnecting load.
- However, Fault Current limiters are lar[illegible], and simpler solutions are possible.
- Probably explains why Fault Current Li[illegible]usiness as usual" on DNO networks.
- I believe fault current monitoring is ne[illegible]at include synchronous Distributed Generators or where the fault level is close to the breaker "making or breaking" capacity.
- Information from fault current monitor could be used to control how a fault is cleared.
  - If the 3-phase fault current is above breaker capacity, perhaps the busbar could be split, or the DG disconnected, prior to tripping the main breaker.

Bournville Resistive Superconducting Fault Current Limiter (Nexan)

Network Innovation Allowance & Competition

- Sharing knowledge from inn ... ects ensures UK customers benefit from the money invested by network compar ...
- Electricity Network Associati ... shared learning through the online Smarter Networks Portal, which is a r ... m the findings from LCNF, NIA and NIC projects.
- Wealth of information is provided across key themes in transmission and distribution of gas and electricity.
- Portal illustrates how different network innovations will contribute to the UK energy future and helps all appreciate why networks are the most dynamic and exciting aspect of our energy industry.
- As UK moves forward, continued innovation via the regulatory framework will be crucial if the UK is to build on the strong start that it has made in the development of future networks.
- Much has been achieved, but there is still a great deal of opportunity to deliver value and savings to customers as new challenges for network companies evolve in the coming years.

[ENA Innovation Portal (energynetworks.org)]

Energy Networks Association’s (ENA) Smarter Networks Portal is a central repository for regulation-funded innovation projects and associated c owledge, news and dissemination events.

Smarter Networks Portal:

- Provides single location for all Ofgem fu Electricity Innovation Projects
- Provides overview of projects, including scope, location, costs, partners and more
- Allows anyone to follow progress and explore outputs
- Promotes communication between Networks and Innovators
- Facilitates innovators to receive calls for ideas and specific requests from Networks
- Provides the opportunity to pitch your innovation ideas directly to ENA and the Network Innovation Managers at any time
- Promotes sharing of information, including datasets from the output of projects
- Provides weekly email updates on projects, refined by individuals chosen interest areas

2015 - 2020, Celsius Project (Electricity North West) = £5.5M

Celsius is an innovative, cost-effective approach to managing potentially excessive temperatures at distribution substations, which may constrain the connection of low carbon technologies.

By delivering new solutions to manage these 'thermal pinch points', Celsius releases additional capacity from existing assets, reduces long-term costs for customers and avoids early asset replacement.

https://smarter.energynetworks.org/

You searched for

University of Exeter

2 results found

Enhance Power Flow Control Capability of GB N

START DATE: Sep 2022 **END DATE:** Nov 2024 **STATUS:** Live

STRATEGY THEMES:
- Net zero and the energy system transition

FUNDING MECHANISM:
- NIA_RIIO-2

Stakeholder attitudes to electricity infrastructure

START DATE: Oct 2013 **END DATE:** Mar 2022

FUNDING MECHANISM:
- Network Innovation Allowance

…nce Power Flow Control Capability (EPFCC) project will investigate the operating …nce of existing Quadrature Boosters and use the resulting knowledge to better …d if new control strategies will allow more effective power flow control and help …uture network constraints. It will also explore how innovative solutions in phase …former designs could deliver transportable modular solutions sufficiently flexible to cope with future demand and the power flow changes during the energy transition. It will also investigate how numerous suitably sized and optimally placed power flow devices can be effectively coordinated to maximise the power transfer capabilities of critical transmission boundaries, whilst minimising risk and ensuring resilience and reliability.

Benefits

The project investigates solutions to enable a wider range of tap moving in post fault action, a coordinated control of multiple QBs, and strategic sizing and location of the power flow control devices to fully utilise the capability of these QB devices and enhance power flow control capability in the network. It'll bring significant benefits on reduced constraint management cost and increased boundary transfer capability of the transmission network, which could delay or reduce the need for new builds and bring cost savings to consumers.

https://smarter.energynetworks.org/

nationalgrid

Stakeholder attitudes to electricity infrastructure

STATUS:
Complete

PROJECT REFERENCE NUMBER:
NIA_NGET0107

START DATE:
Oct 2013

END DATE:
Mar 2022

Contact Lead Network

Project summary

FUNDING MECHANISM:
- Network Innovation Allowance

TECHNOLOGY:
- Stakeholder Engagement

EXPENDITURE:
£160,000

This project looked to explore the public perception of consultations for large infrastructure projects and [illegible]earch problem of underlying public disengagement with this process. The[illegible]ed out in this project contributes conceptually, methodologically and empirica[illegible]g the research problem through a high voltage overhead powerline ca[illegible]ch design in Cumbria. The outcomes from this research are both theoreti[illegible]al. The conceptual framework and research methods (theoretical) [illegible]d to a novel academic approach to investigating public engagement with the energy industry and the empirical output will help to inform the development of public engagement strategies in practice.

Presentations covering work carried out in the project around topics such as communities, engagement and planning were given at the following events:

1. '*Hard to Reach or Hard to Engage?*' - Energy and Communities Seminar, July 2015, University of Exeter
2. *The seldom-heard voice in public engagement with major infrastructure* - UK Ireland Planning Research Conference 2016, Cardiff University
3. *Exploring public disengagement from proposed overhead powerline consultation processes through a Bourdieuian lens* - 4th Energy and Society Conference, 2018, University of Exeter
4. *Public disengagement from the decision-making process for Nationally Significant Infrastructure projects* - Exeter Energy 5th Making Sense of Sustainable Energy Systems Seminar, 2019, University of Exeter
5. *Exploring public disengagement from consultation processes for major infrastructure through a Bourdieusian lens* - UK Ireland Planning Research Conference, 2019, University of Liverpool
6. *Investigating the role of symbolic violence in understanding public disengagement from planning for energy infrastructure* - Royal Geographical Society Annual International Conference, 2021.
7. *Investigating public disengagement from planning for major infrastructure projects: A high voltage powerline case study – Findings and reflections*, University of Exeter Economic & Social Research Group presentation, May 2022.

Any Questions?

$$E = mc^2$$

Net-Zero Energy needs secure measurements, Control & Communications