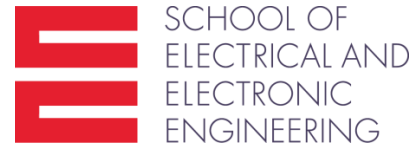


Renewable Energy Integration on Low-Voltage Distribution Networks

Dr. Keith Sunderland (EPRC and DEL)

School of Electrical and Electronic Engineering



Wednesday, 20th May

DIT Grangegorman



Overview

- Research Motivation
- Current Work
- Future work.... Research potential

Motivation

Smart Network – Smart Cities

DwG; DpvG; DS; PQ concerns

Climate modelling as a driver

National/International Context

Smarter
Distribution
Network
Modelling
Test Bed

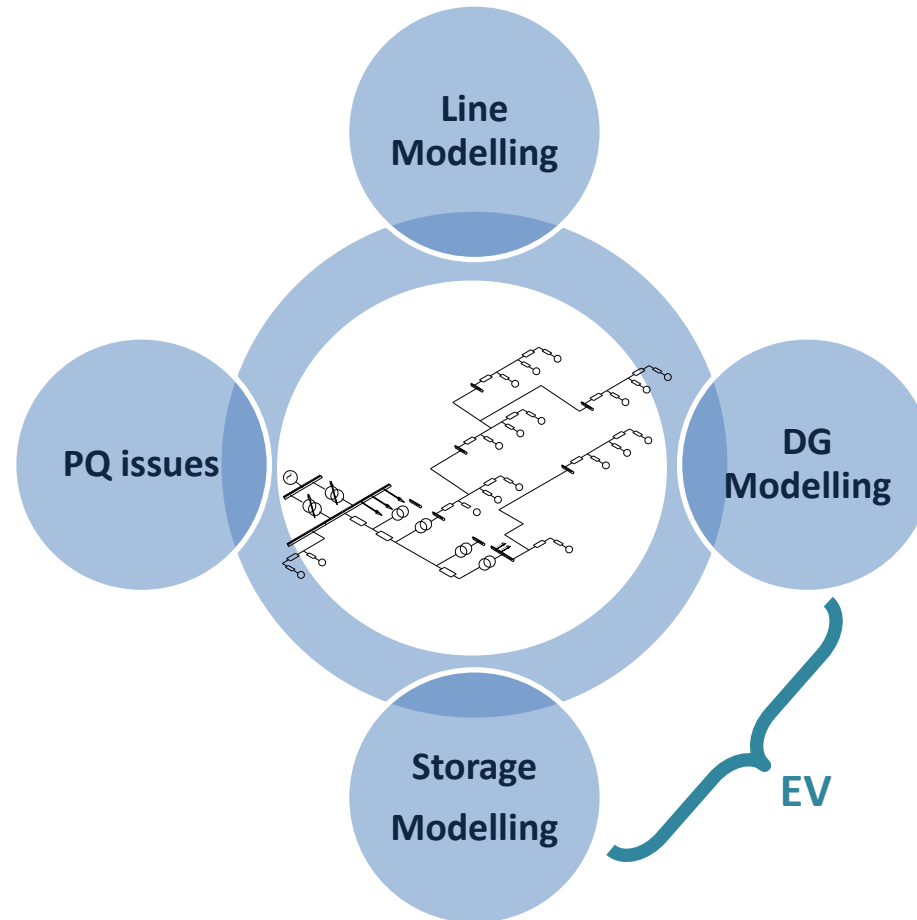
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Slide 1

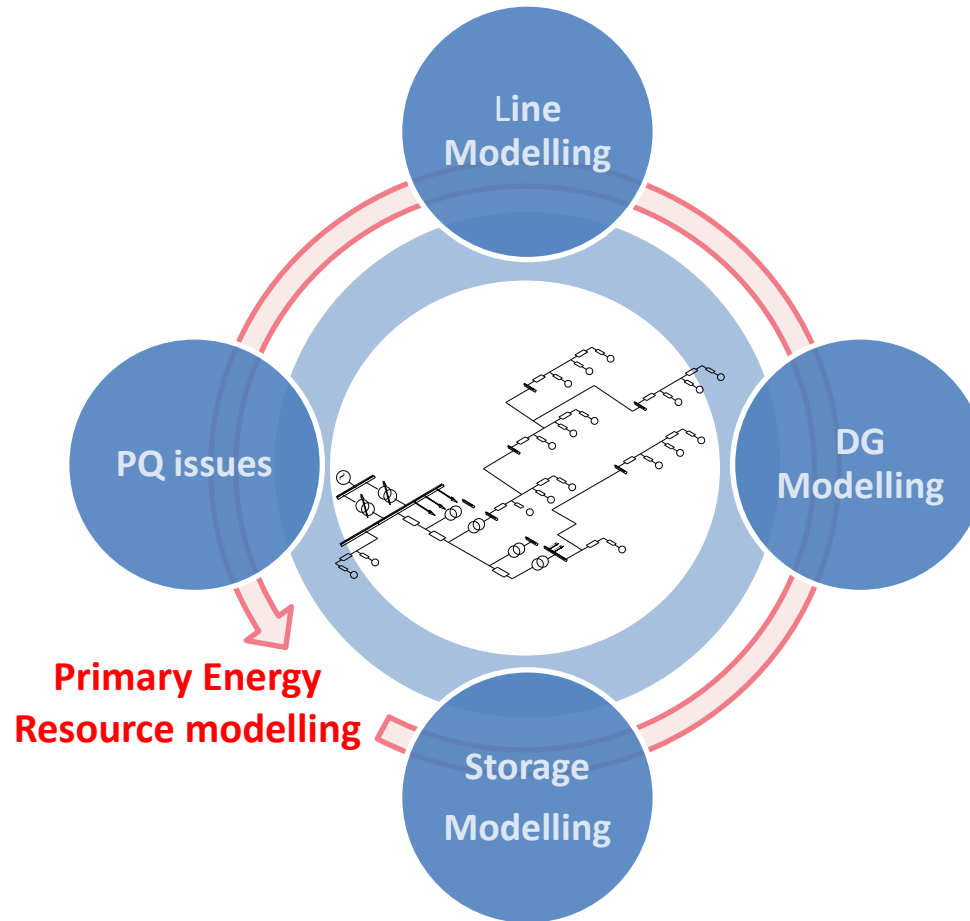
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Slide 1

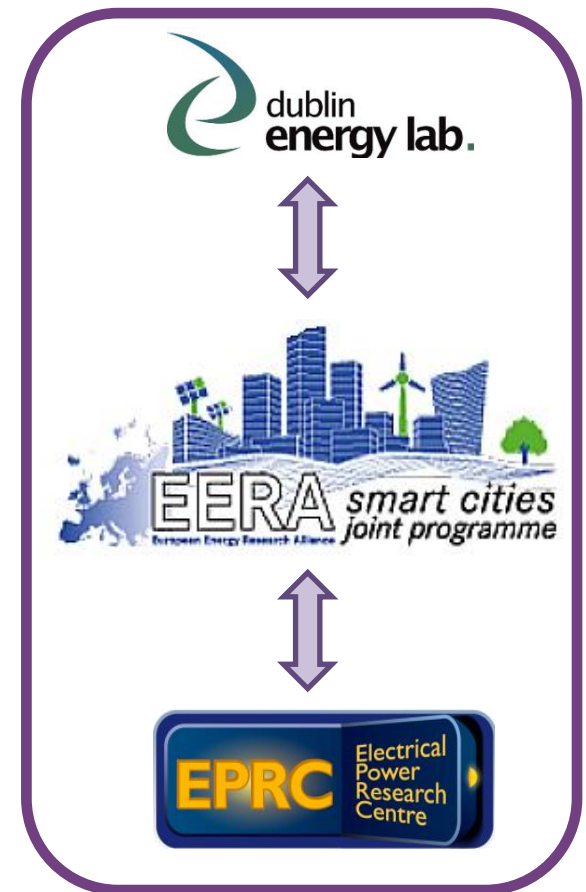
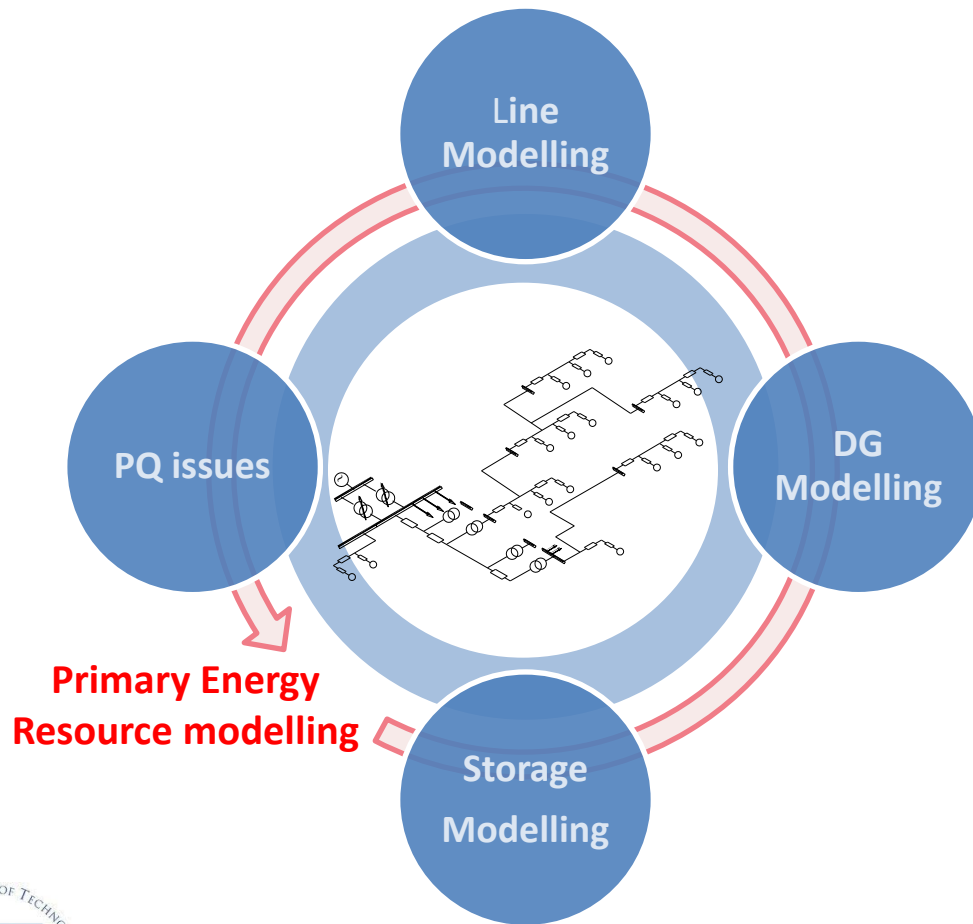
Motivation

Smart Network – Smart Cities

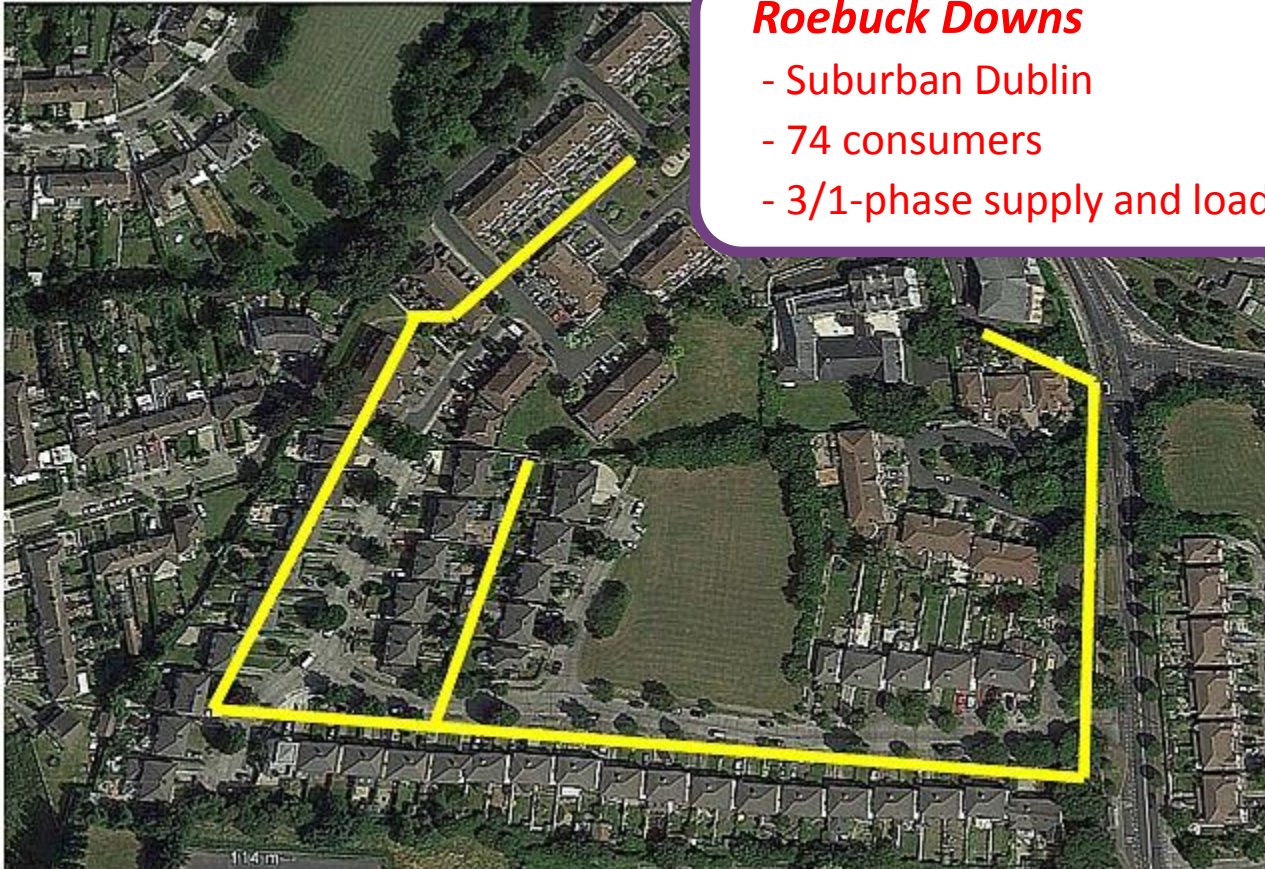
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Climate modelling as a driver

National/International Context



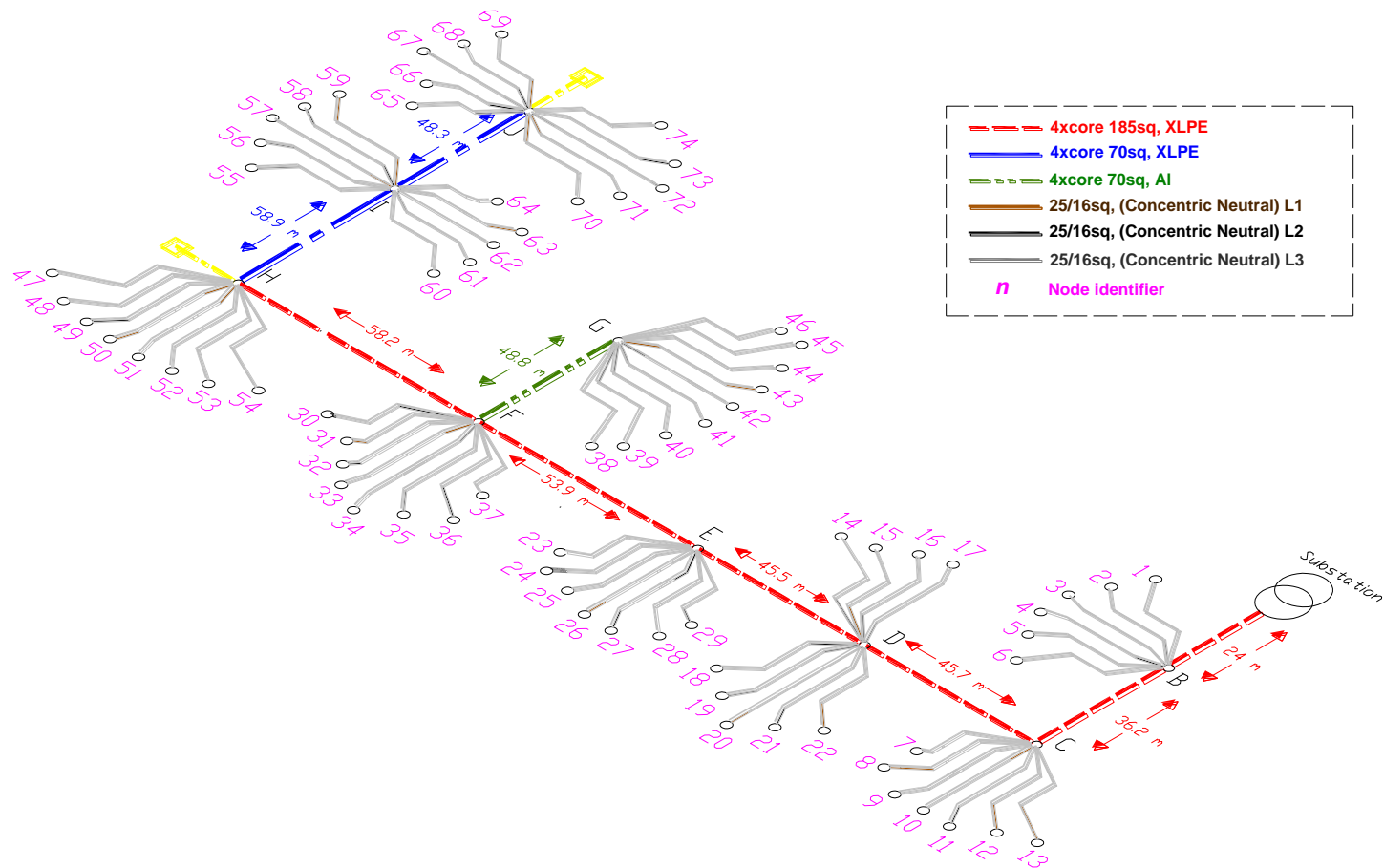
Current work



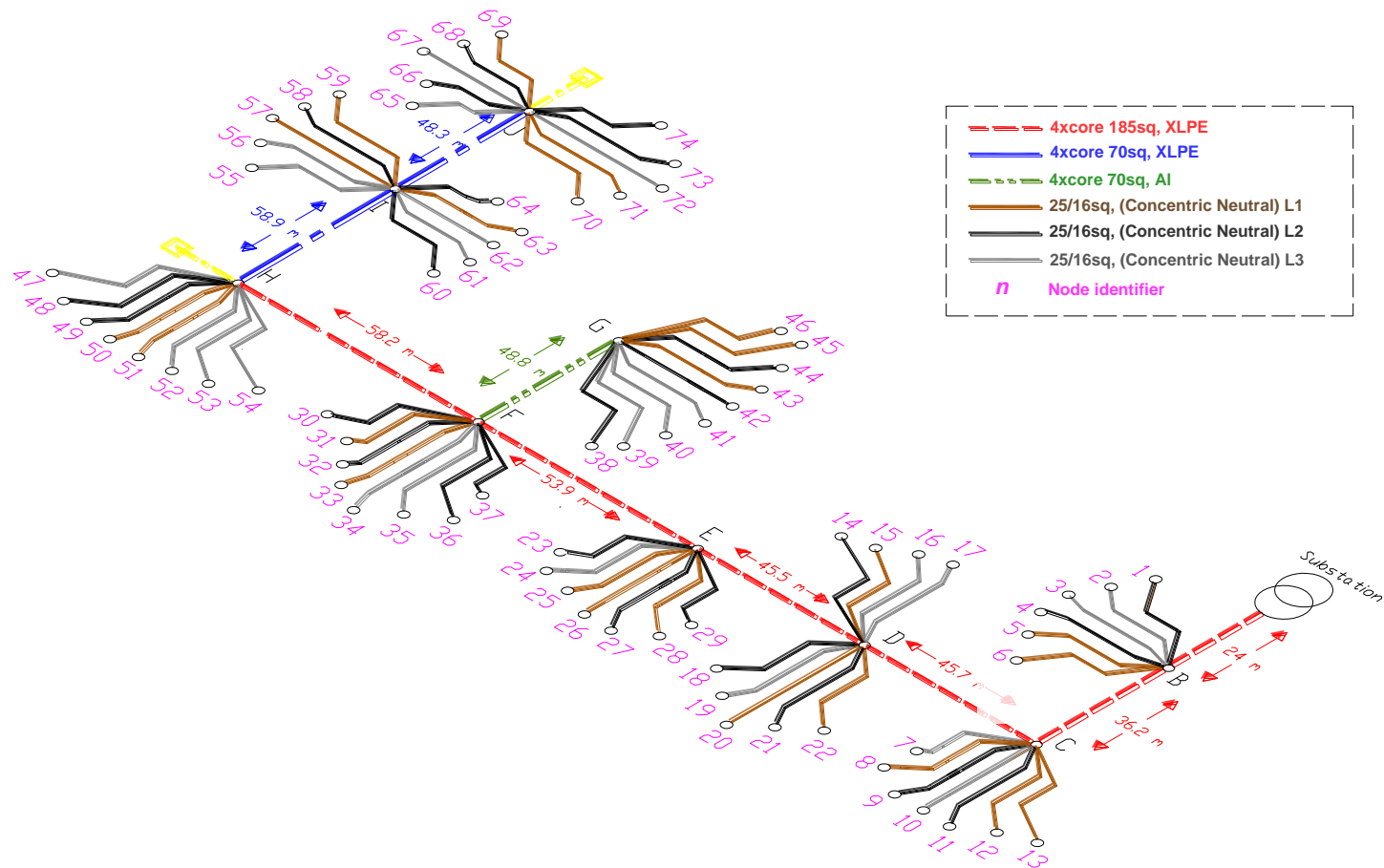
Roebuck Downs

- Suburban Dublin
- 74 consumers
- 3/1-phase supply and load connections

Current work



Current work



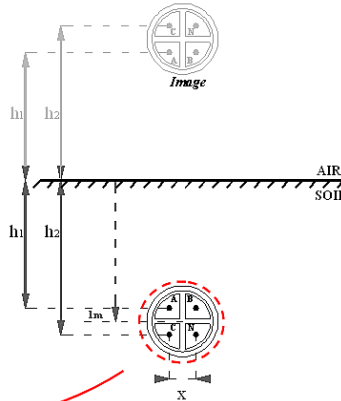
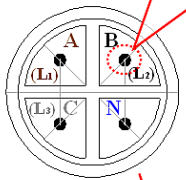
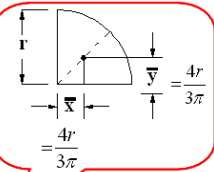
Network Line consideration

System Earthing

Power Flow incorporating DwG/DpvG

LCOE analysis (DwG)

Current work

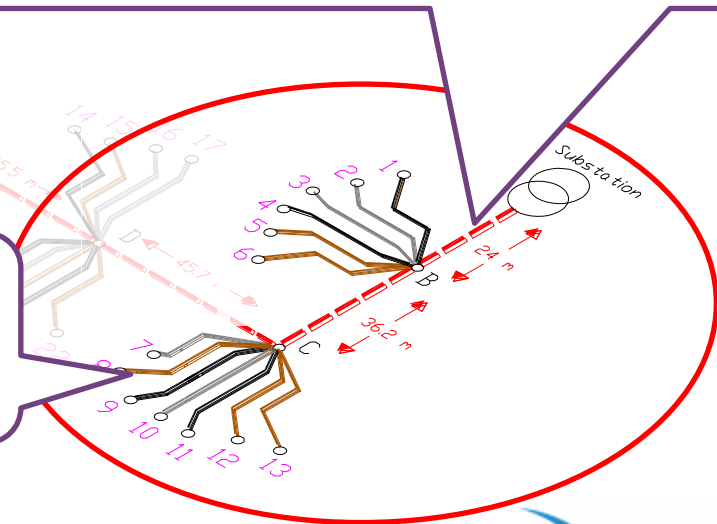
Identifying the
centre-point of
each quadrant

Detail on conductor spacing



$$Z_{185\text{mm}^2} = \begin{bmatrix} 21.63 + 74.97i & 4.93 + 0.68.73i & 4.93 + 68.73i & 4.93 + 66.55i \\ 4.93 + 68.73i & 21.63 + 0.74.97i & 4.93 + 66.55i & 21.63 + 68.73i \\ 21.63 + 68.73i & 21.63 + 0.66.55i & 21.63 + 74.97i & 21.63 + 68.73i \\ 21.63 + 66.55i & 21.63 + 0.68.73i & 21.63 + 68.73i & 21.63 + 74.97i \end{bmatrix} \times 10^{-5}$$

$$Z_{an} = \begin{bmatrix} Z_{ii} & 0 & 0 & Z_{ij} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ Z_{ji} & 0 & 0 & Z_{jj} \end{bmatrix}$$

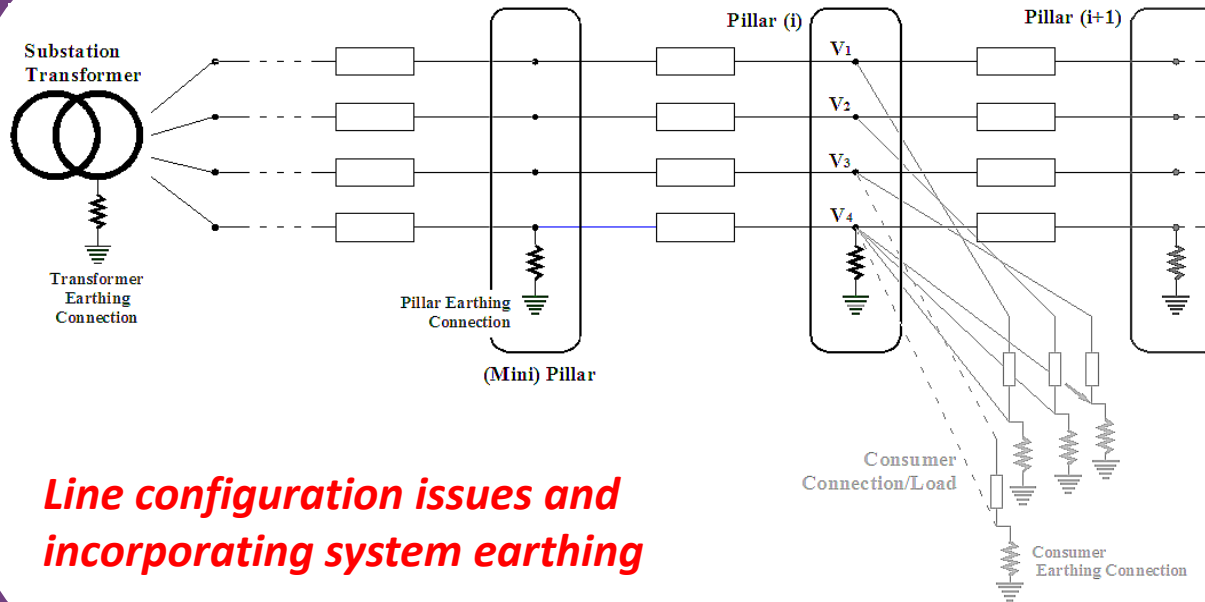


System Earthing

Power Flow incorporating DwG/DpvG

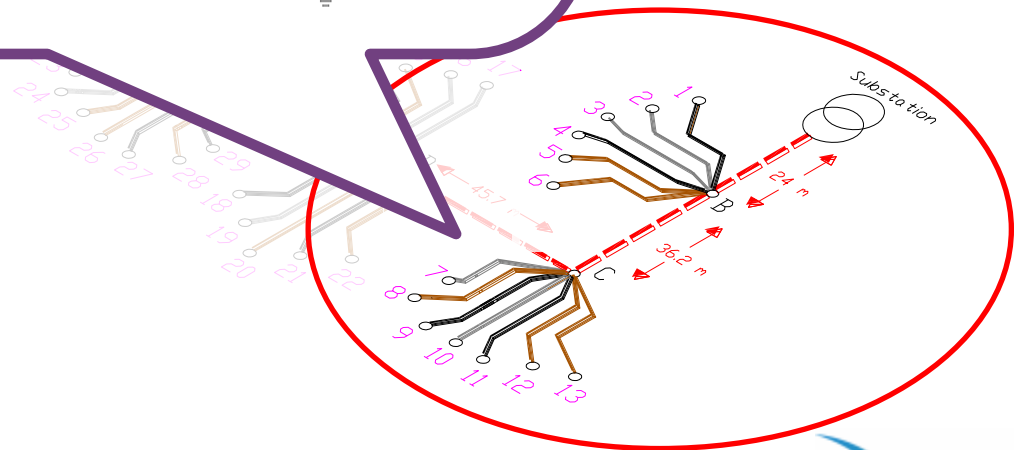
LCOE analysis (DwG)

Current work

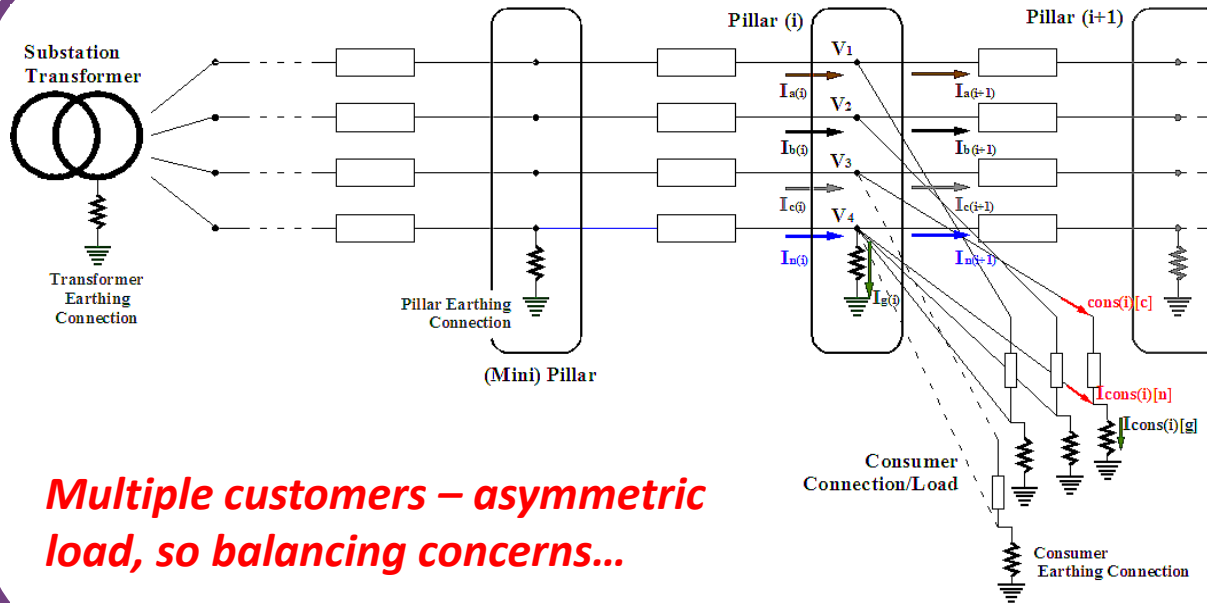


Line configuration issues and incorporating system earthing

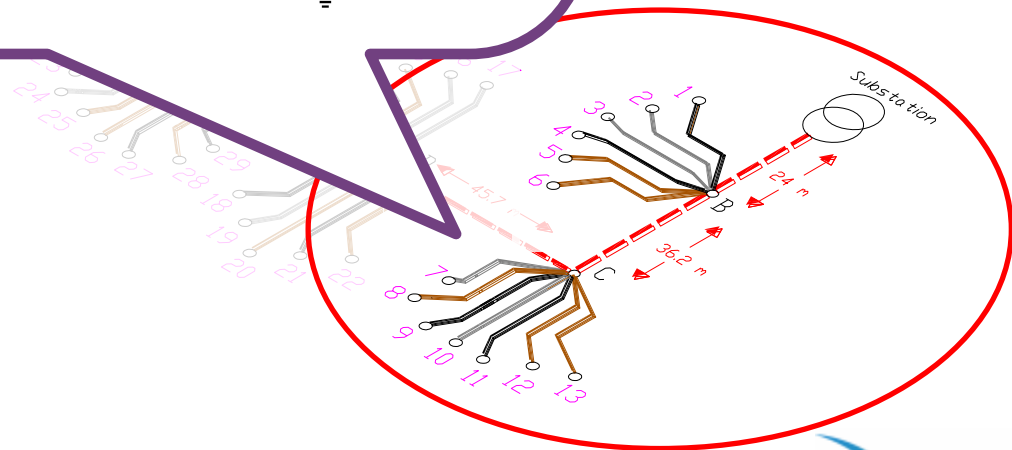
4xcore 185sq, XLPE
 4xcore 70sq, XLPE
 4xcore 70sq, Al
 25/16sq, (Concentric Neutral) L1
 25/16sq, (Concentric Neutral) L2
 25/16sq, (Concentric Neutral) L3
 Node identifier



Current work



Multiple customers – asymmetric load, so balancing concerns...



Current work

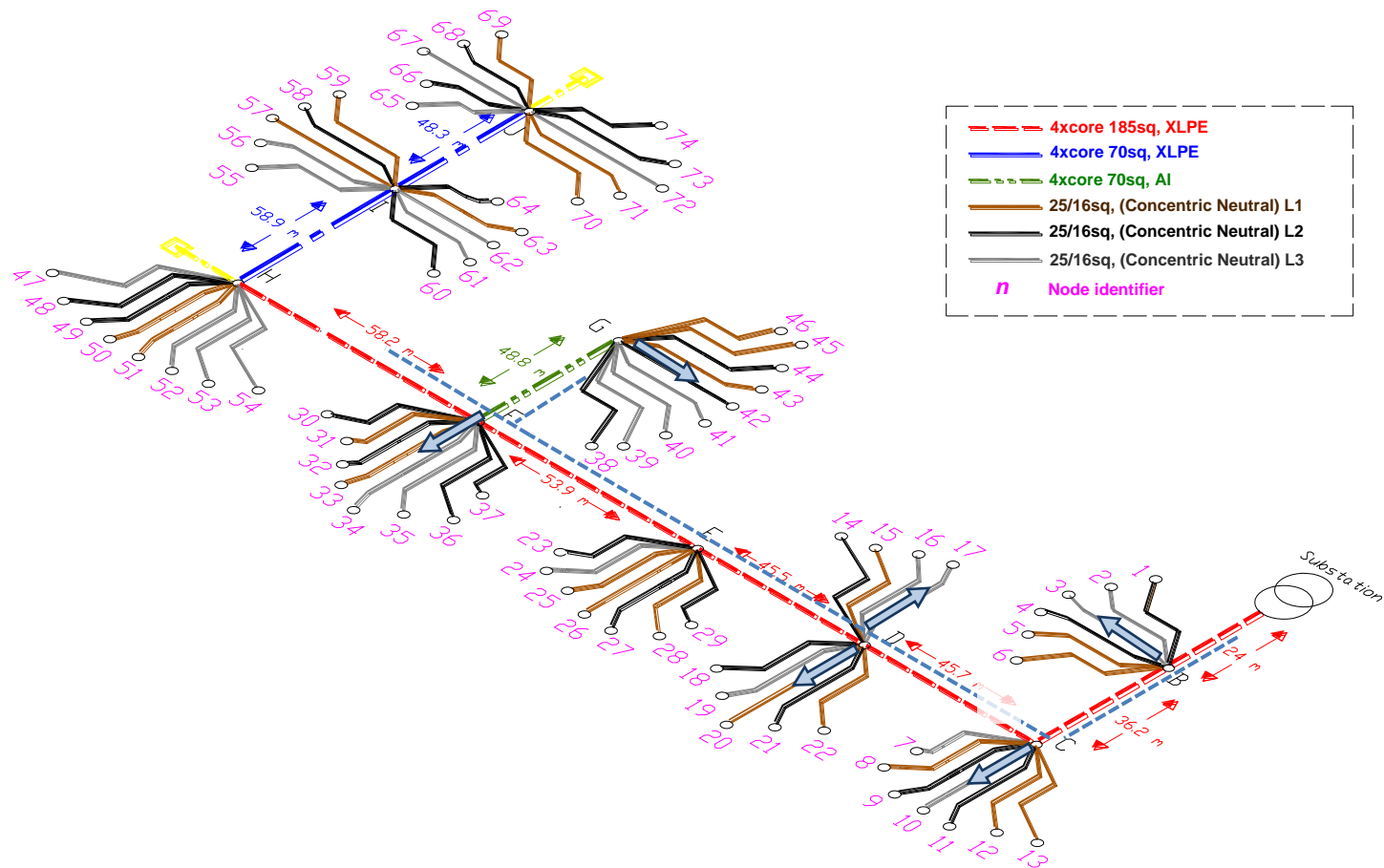
Distribution Network Model

Network Line consideration

System Earthing

Power Flow incorporating DwG/DpvG

LCOE analysis (DwG)



Current work

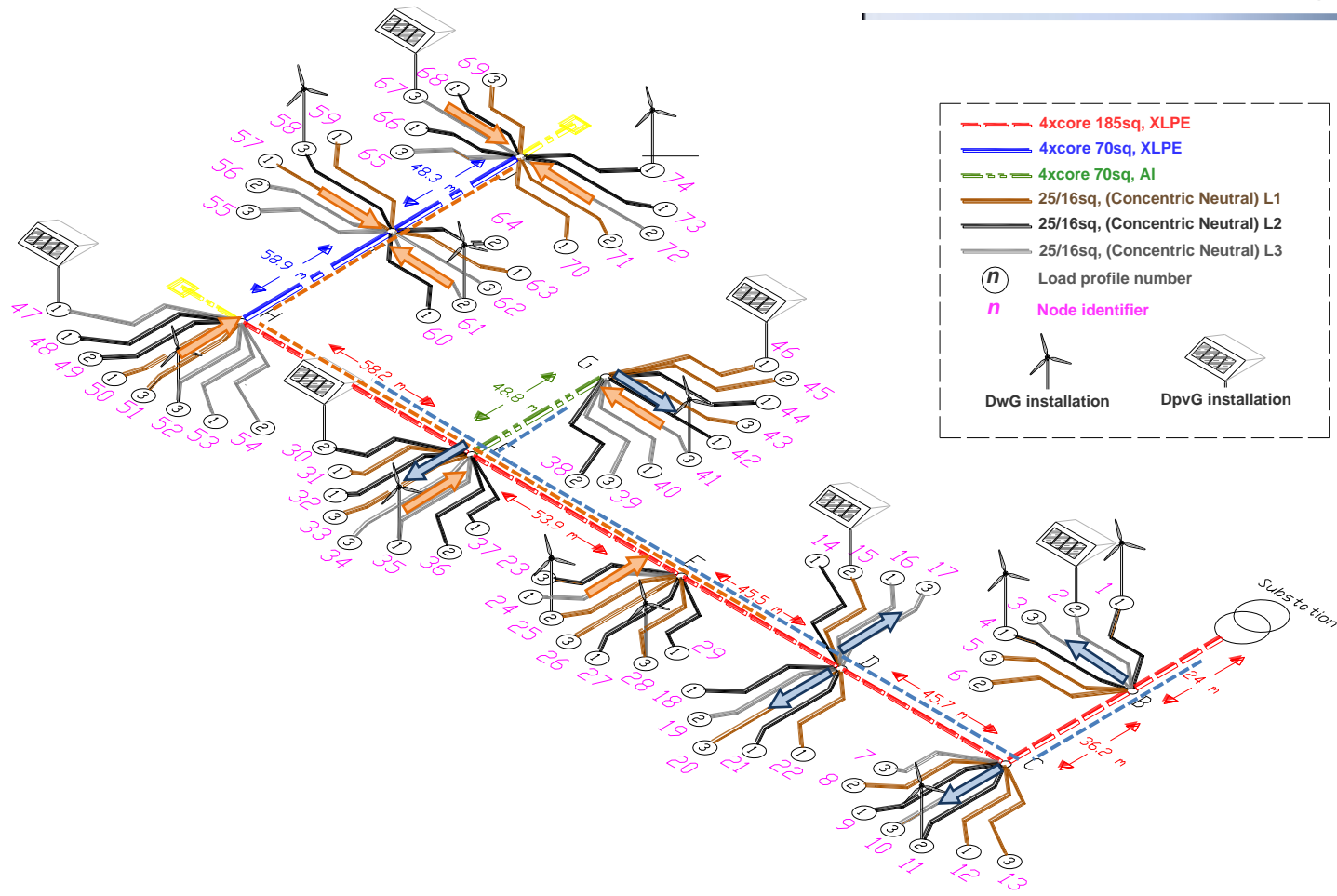
Distribution Network Model

Network Line consideration

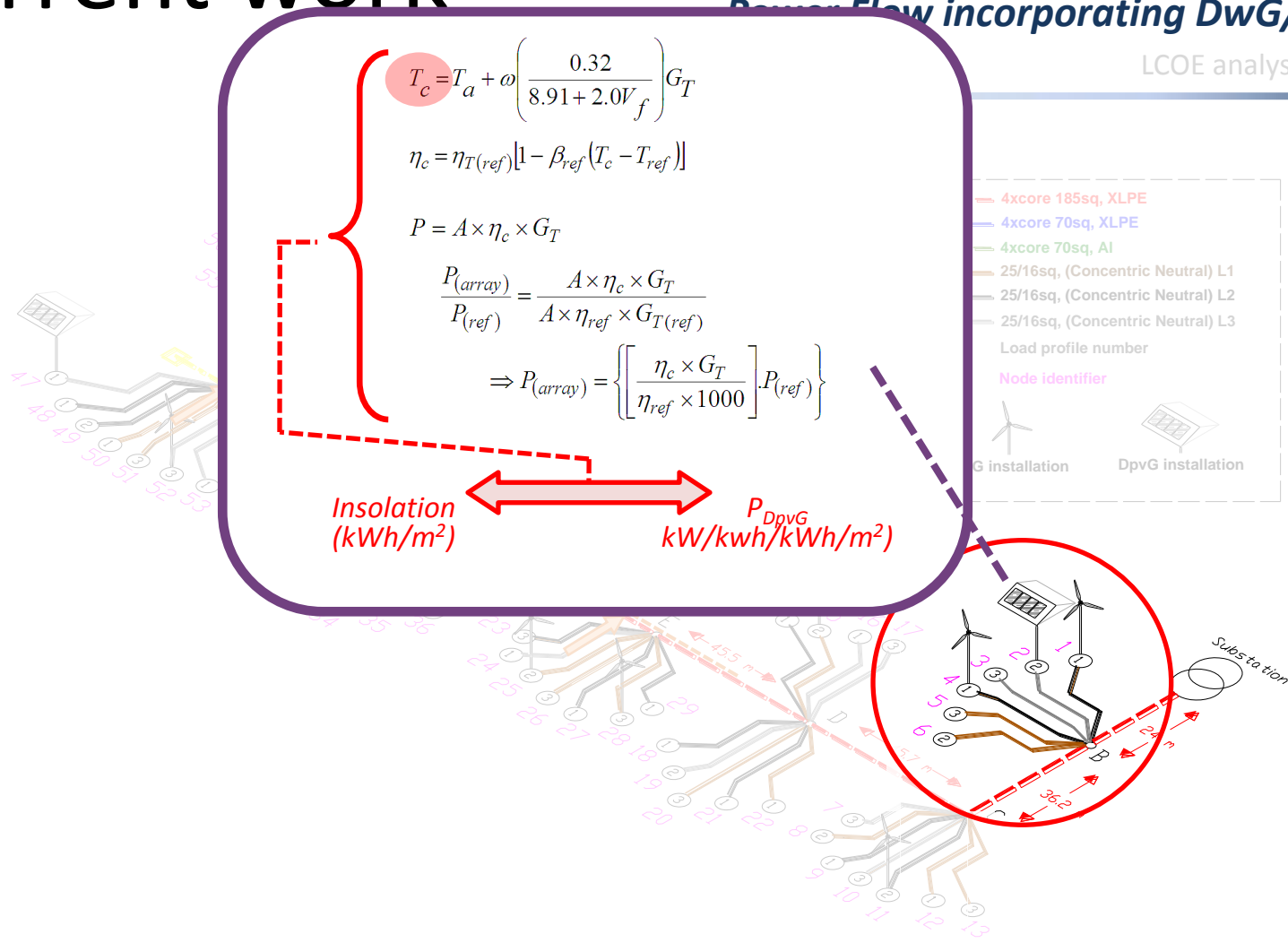
System Earthing

Power Flow incorporating DwG/DpvG

LCOE analysis (DwG)



Current work



Current work

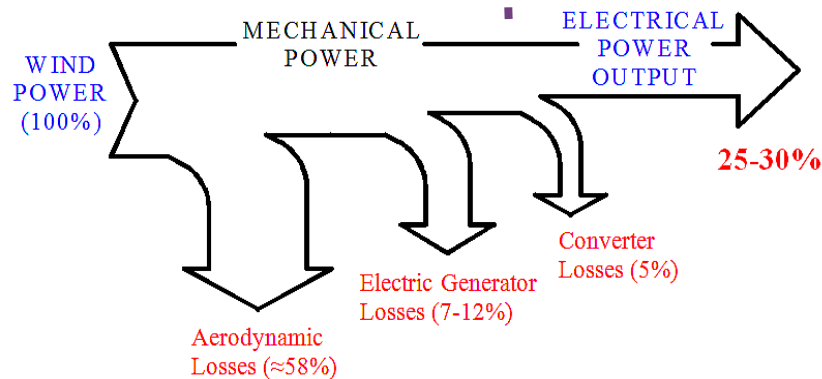
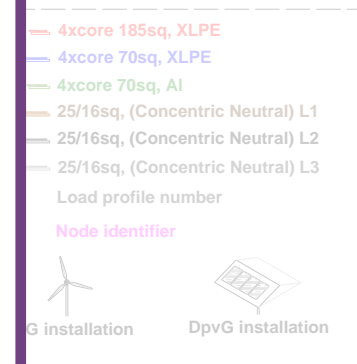
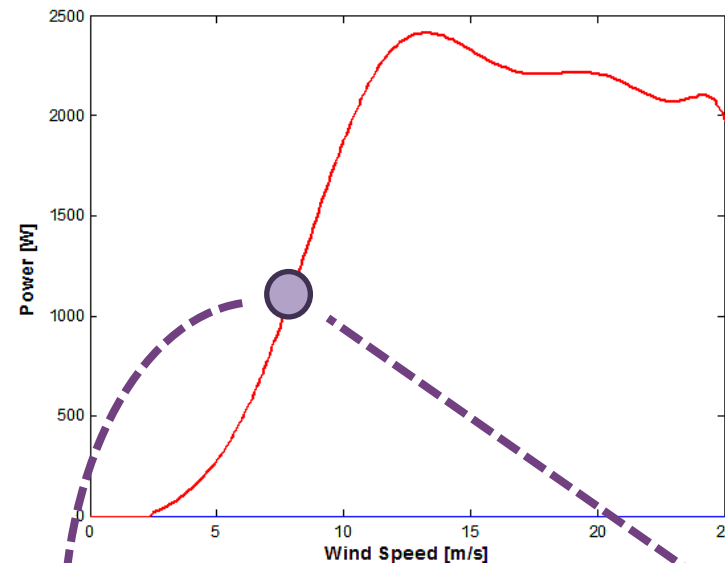
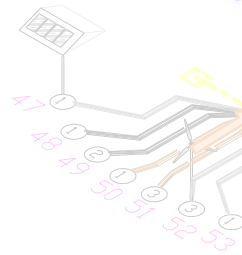
Distribution Network Model

Network Line consideration

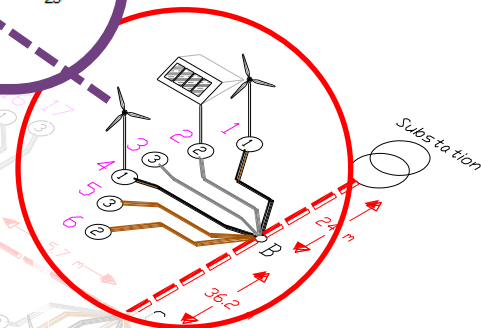
System Earthing

Power Flow incorporating DwG/DpvG

LCOE analysis (DwG)



Slide 7



Current work

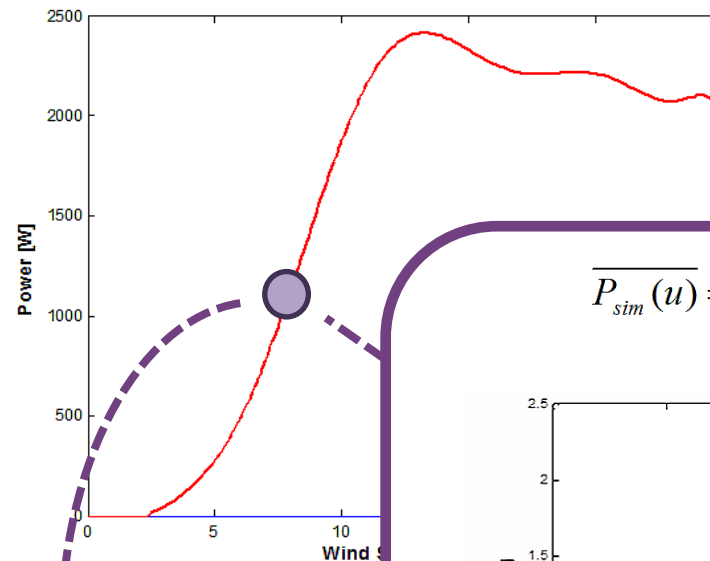
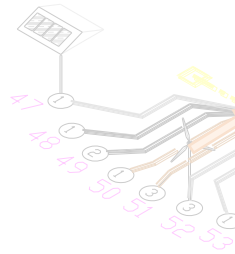
Distribution Network Model

Network Line consideration

System Earthing

Power Flow incorporating DwG/DpvG

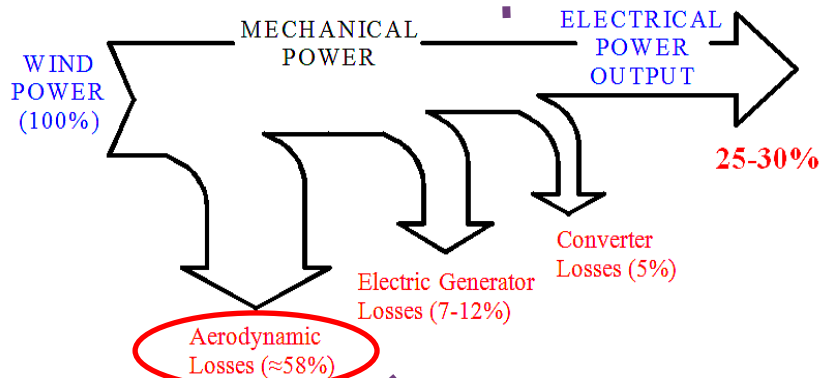
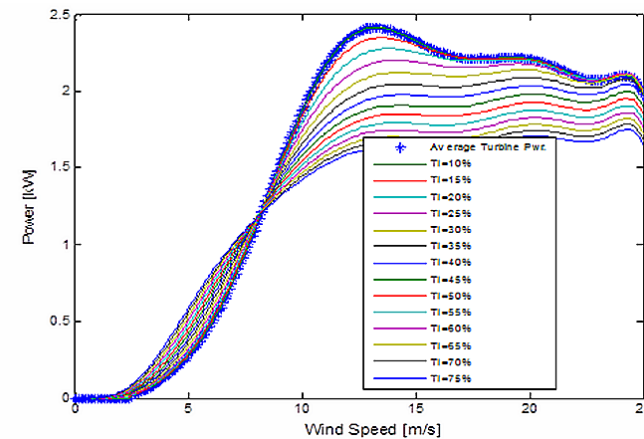
LCOE analysis (DwG)



4xcore 185sq, XLPE
4xcore 70sq, XLPE
4xcore 70sq, Al

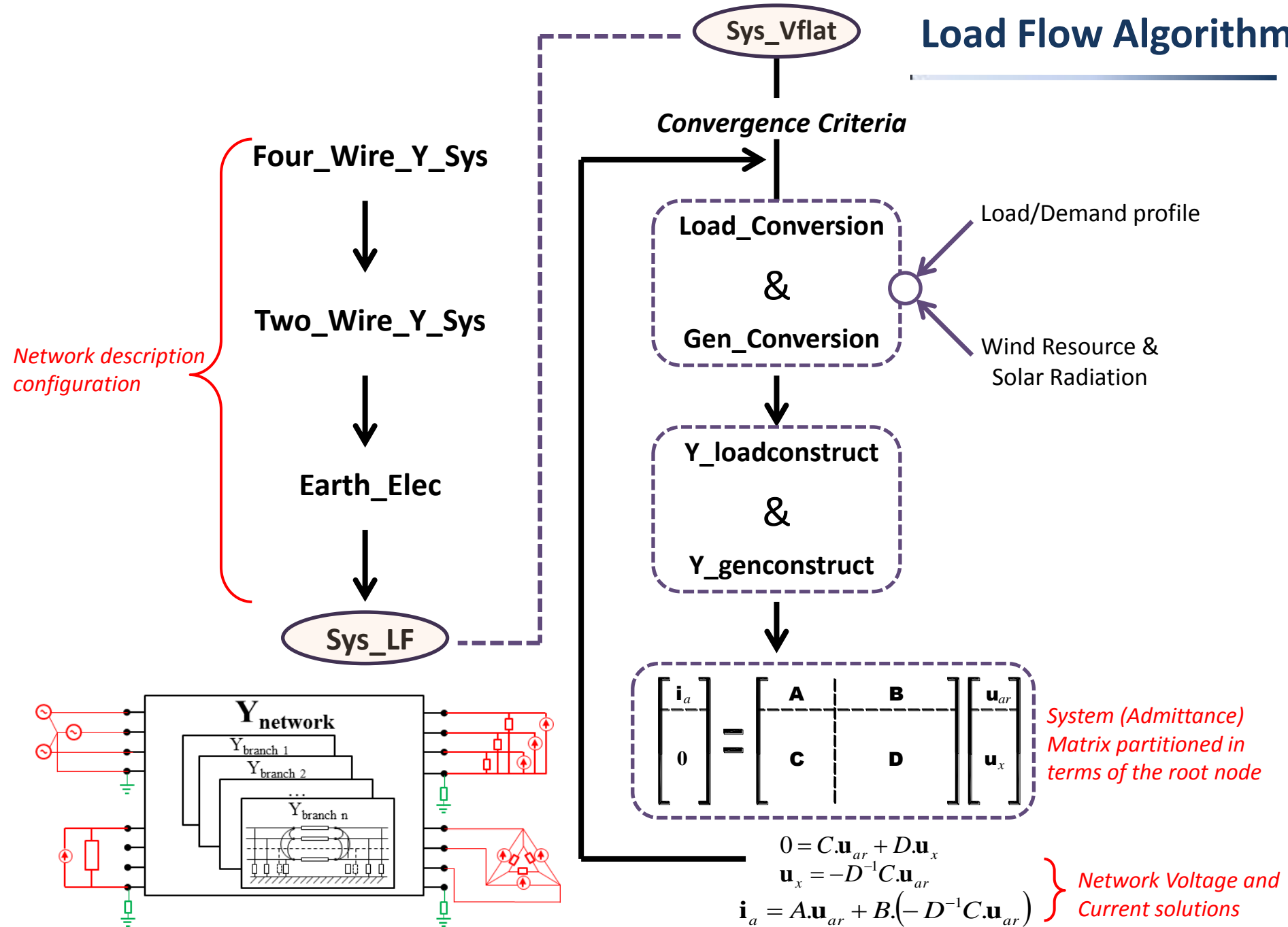
$$\overline{P_{sim}(u)} = \int_{u=0}^{\infty} P_{I=0}(u) \cdot f(u) du$$

$$\sigma = TI \times \bar{u}$$



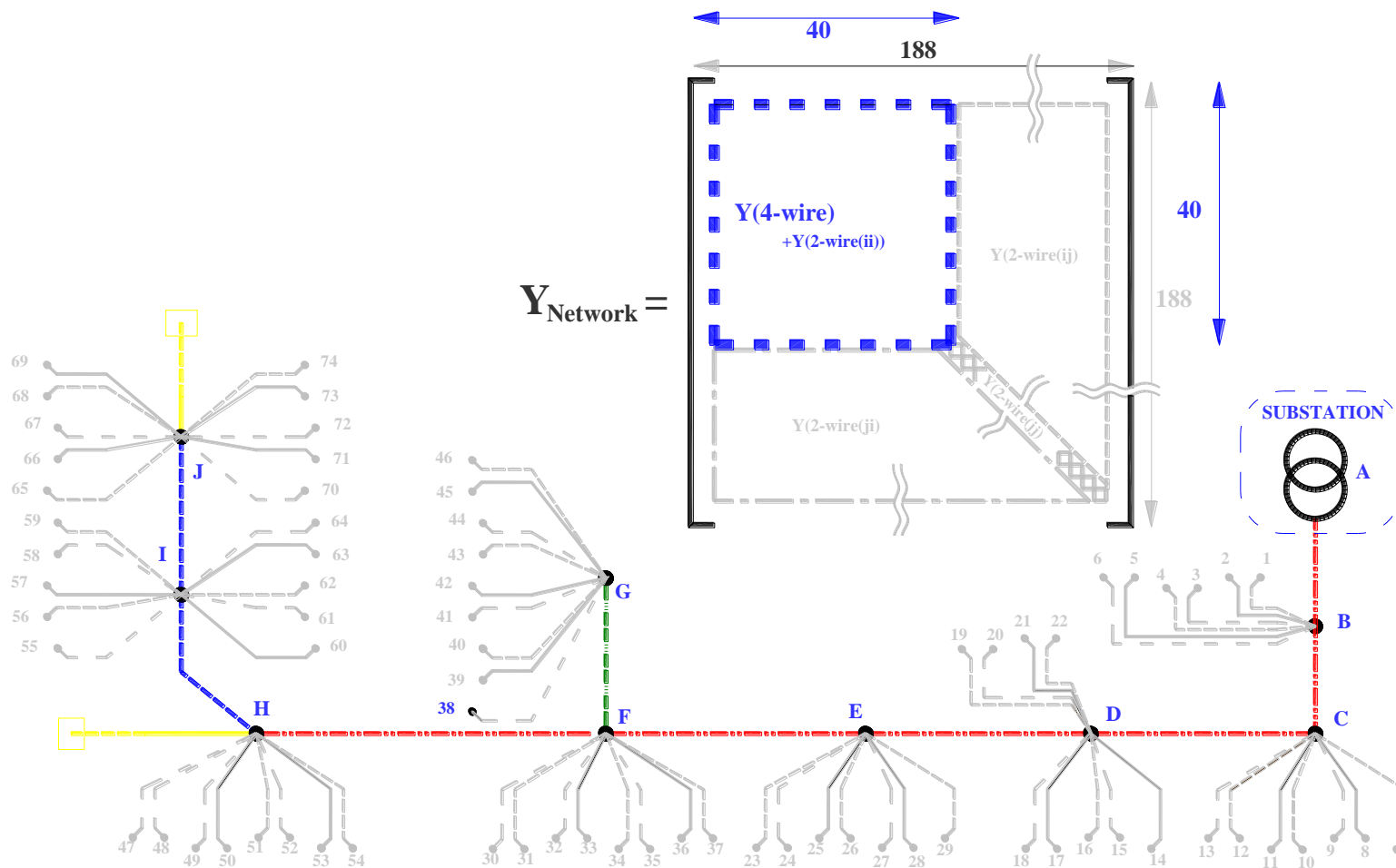
Slide 7

Admittance Correction Load Flow Algorithm



Admittance Correction Load Flow Algorithm

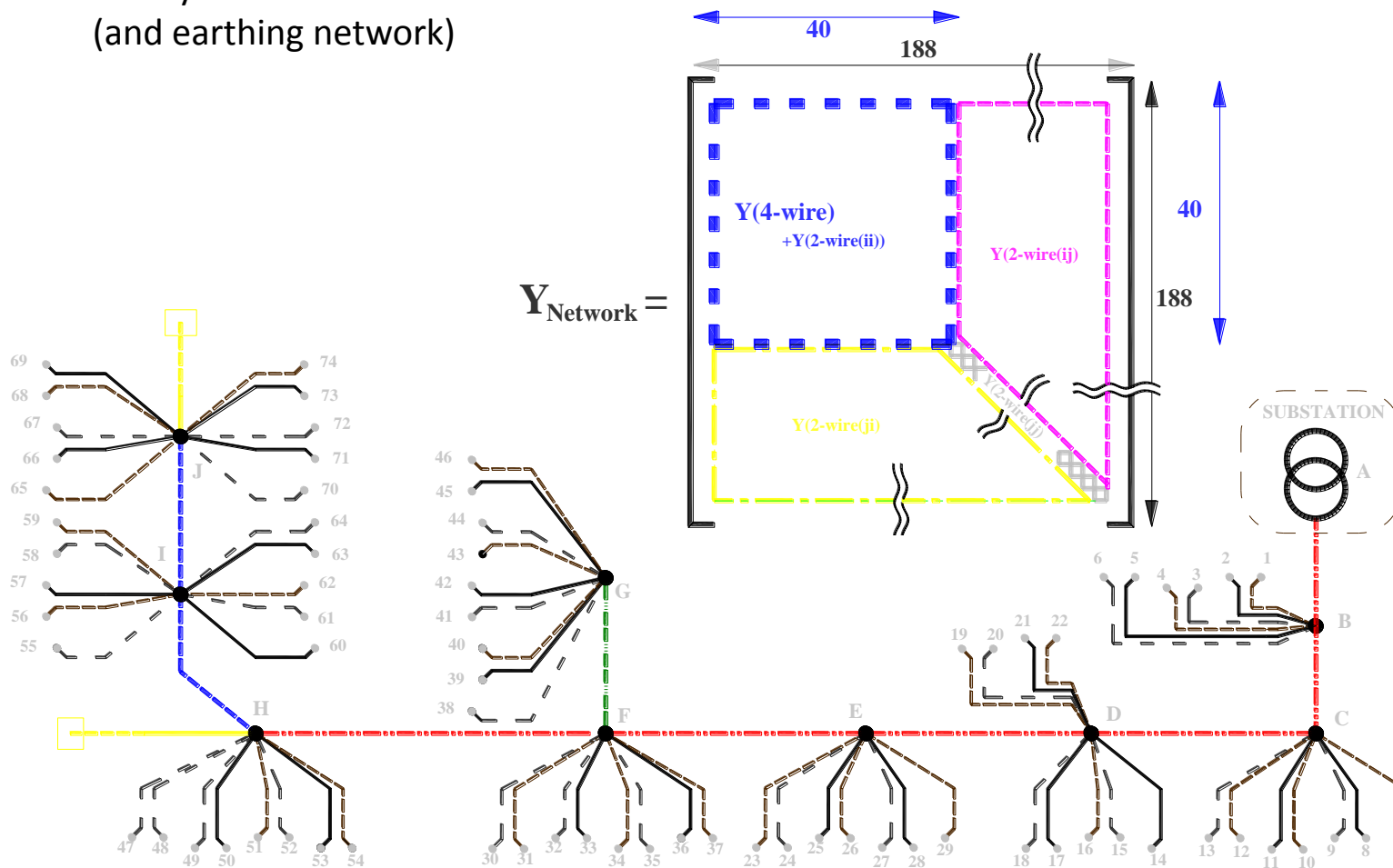
1. The 4-wire (Backbone) consisting of branch connections from distribution transformer to network mini-pillars (9 no.)



Admittance Correction Load Flow Algorithm

1. The 4-wire (Backbone) consisting of branch connections from distribution transformer to network mini-pillars (9 no.)

2/3. The single-phase line connections are facilitated within the system admittance matrix (and earthing network)

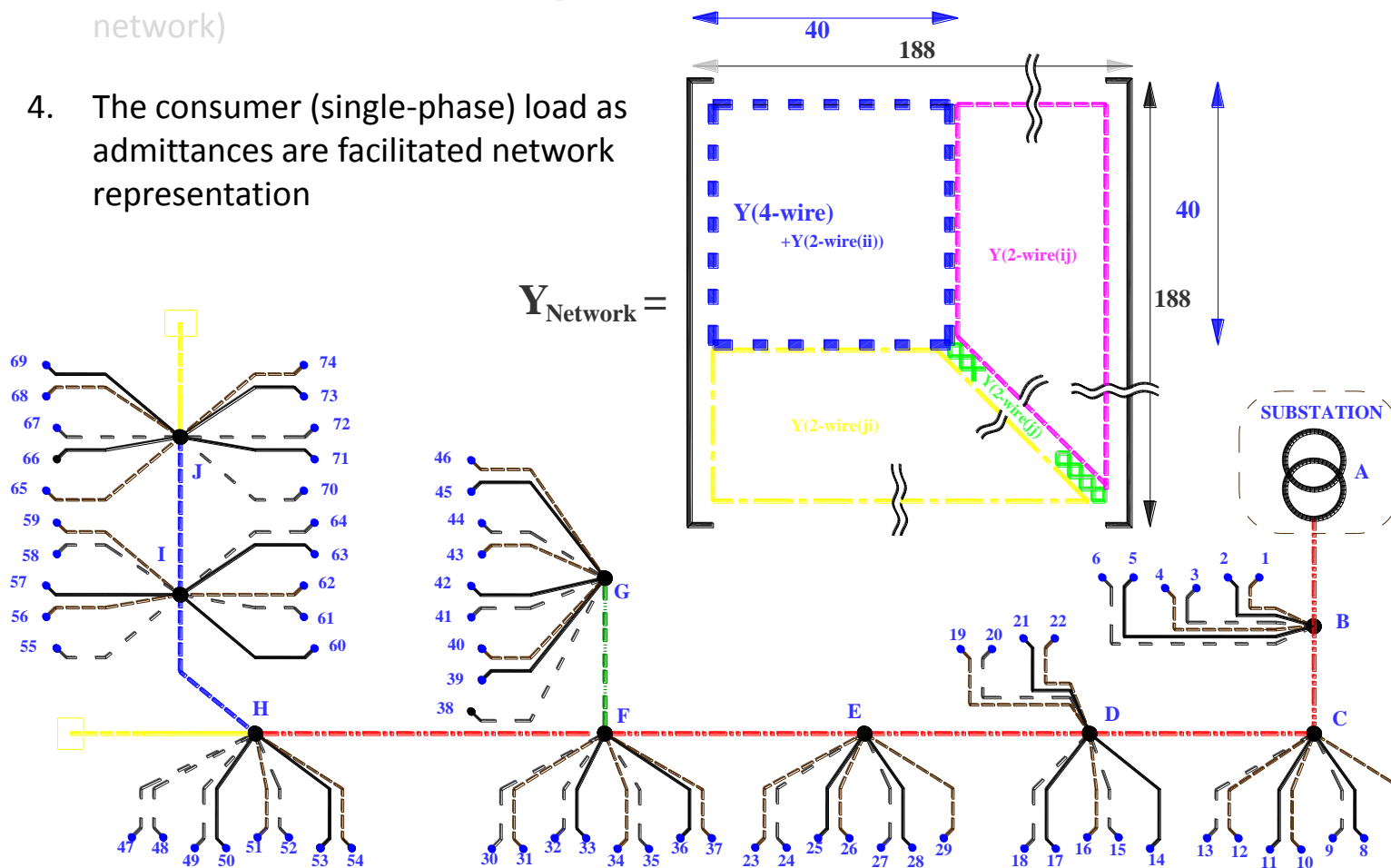


Admittance Correction Load Flow Algorithm

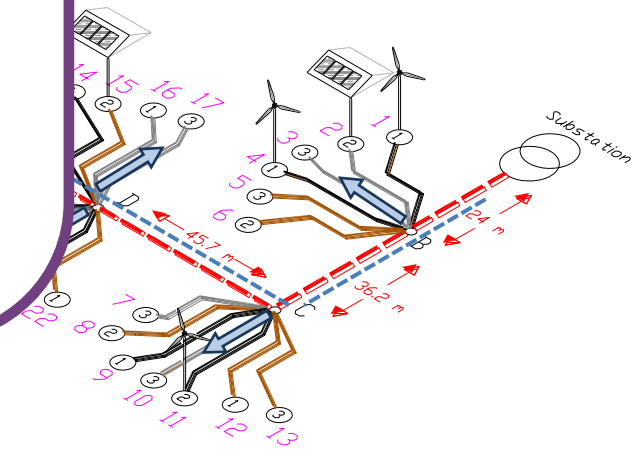
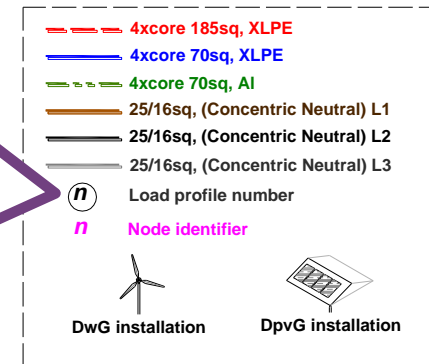
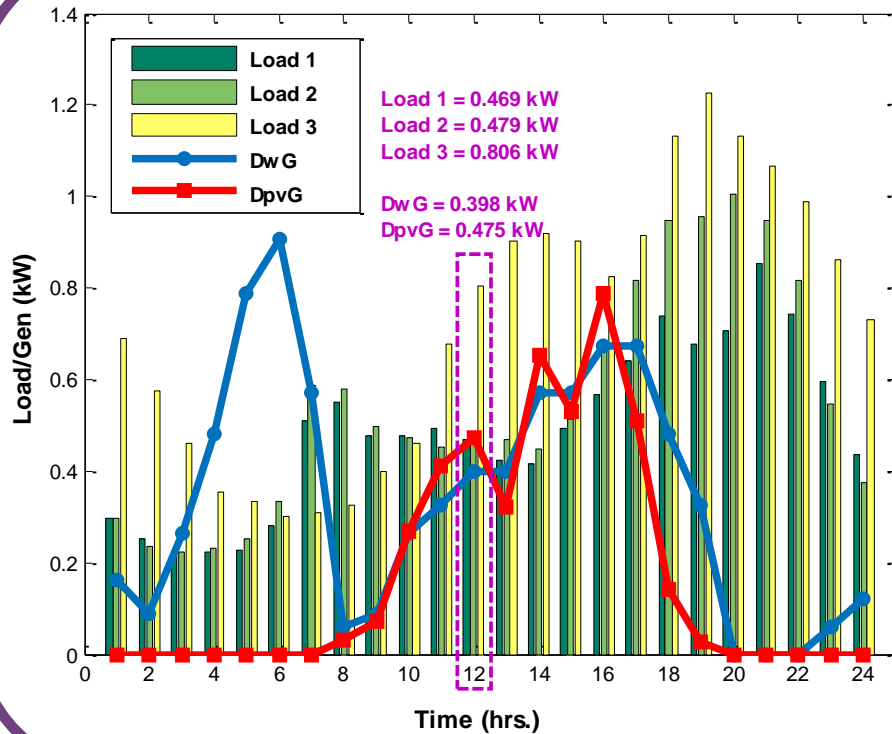
1. The 4-wire (Backbone) consisting of branch connections from distribution transformer to network mini-pillars (9 no.)

2/3. The single-phase line connections are facilitated within the system admittance matrix (and earthing network)

4. The consumer (single-phase) load as admittances are facilitated network representation



Current work



Current work

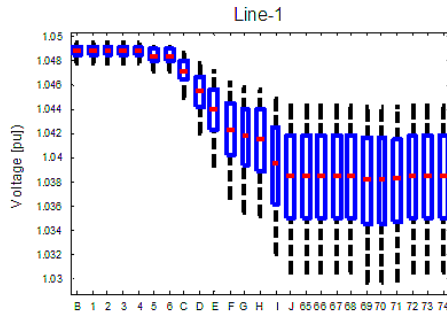
Distribution Network Model

Network Line consideration

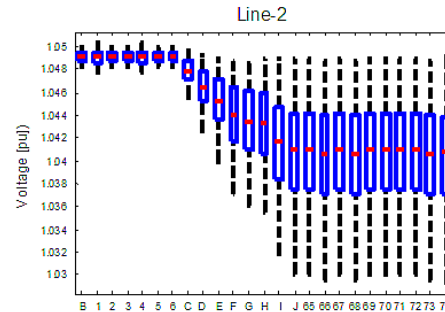
System Earthing

Power Flow incorporating DwG/DpvG

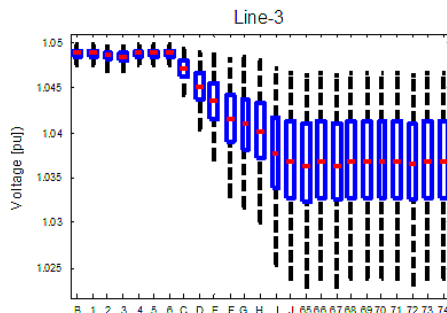
LCOE analysis (DwG)



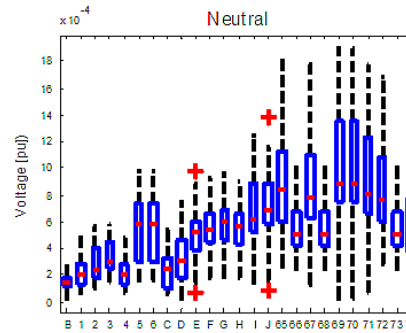
Pillar/Customer



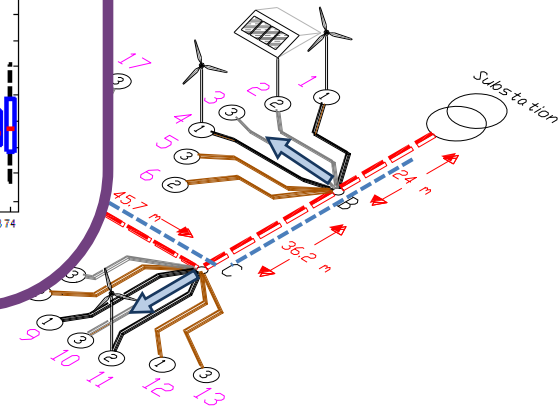
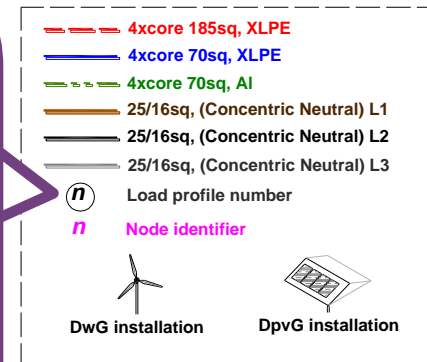
Pillar/Customer



Pillar/Customer



Pillar/Customer



Current work

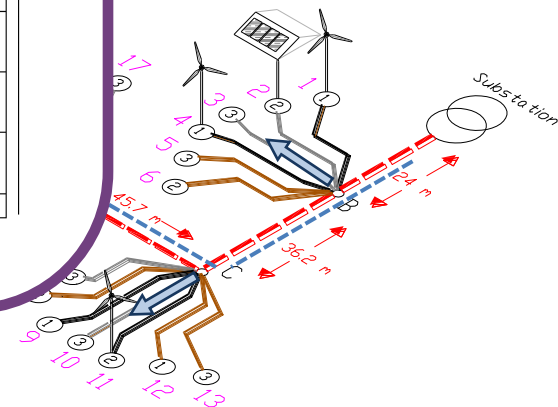
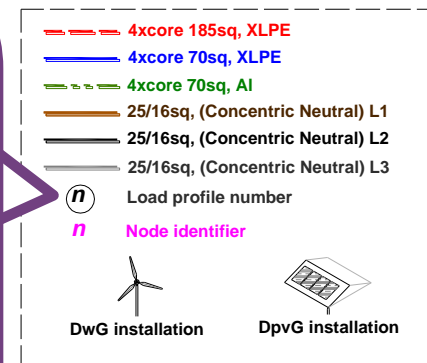
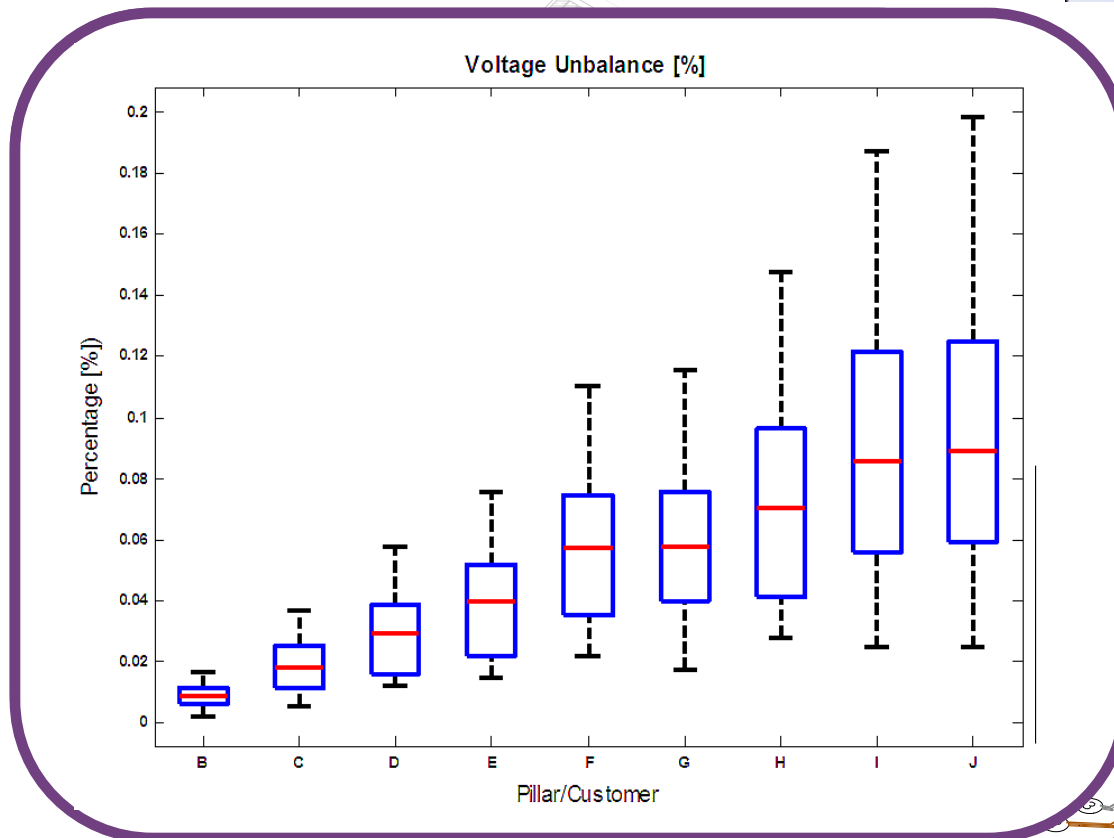
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Current work

Distribution Network Model

Network Line consideration

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Power Flow incorporating DwG/DpvG

LCOE analysis (DwG)

Turbine Hub Height (z_{WT}) [m]	Anemometer Height (z_{WT}) [m]	Surface Roughness, (z_0) [m]	
20	10	0.02	Dublin Airport (Rural)
	26	1.1	Dublin (Urban)

VAT	23%
Real interest rate	5.0%
(System) cost of Turbine (€)	€14,520
Annual Maintenance Cost (€)	€436
Capacity of Turbine (kW)	2.40
Cost/kW	€6,050
Unit cost (purchase)	€0.18
Unit Cost (Sale)	€0.09

Current work

Distribution Network Model

Network Line consideration

System Earthing

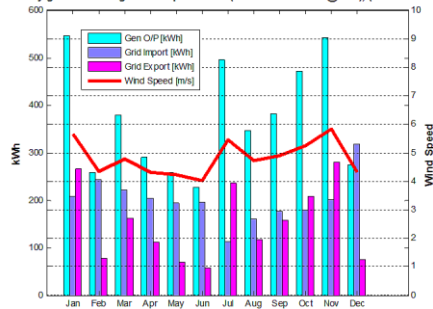
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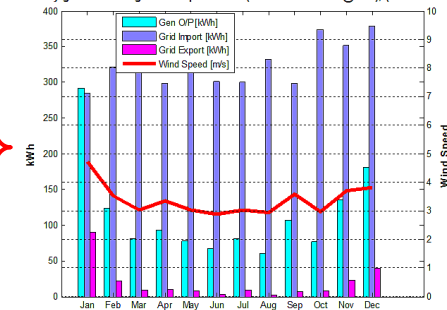
Monthly generation & grid sales/purchases (u-mean of 5.4m/s @20m), (Rural Dublin)



Annual Energy Production (Ireland) and cost of energy production by the wind turbine (kWh)

DUBLIN AIRPORT (Rural)									
Annual Mean Wind Speed									
	3m/s	4m/s	5m/s	5.36m/s	6m/s	7m/s	8m/s	9m/s	
Initial Cost per 1kW/Installation	€9,076	€2.95	€1.16	€0.63	€0.54	€0.42	€0.31	€0.25	€0.21
	€7,563	€2.46	€0.97	€0.53	€0.45	€0.35	€0.26	€0.21	€0.18
	€6,050	€1.96	€0.77	€0.42	€0.36	€0.28	€0.21	€0.17	€0.14
	€4,538	€1.47	€0.58	€0.32	€0.27	€0.21	€0.15	€0.12	€0.11
	€3,025	€0.98	€0.39	€0.21	€0.18	€0.14	€0.10	€0.08	€0.07
	€1,513	€0.49	€0.19	€0.11	€0.09	€0.07	€0.05	€0.04	€0.04
	815	2073	3790	4447	5753	7751	9619	11203	
AEP (kWh/ $U_{Mean(annual)}$)									
DUBLIN (Urban)									
Annual Mean Wind Speed									
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	894	1339	2227	4014	6040	8000	9719	11141	
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Monthly generation & grid sales/purchases (u-mean of 3.4m/s @20m), (Urban Dublin)



Current work

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Network Line consideration

System Earthing

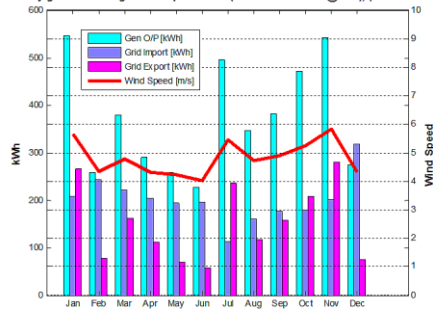
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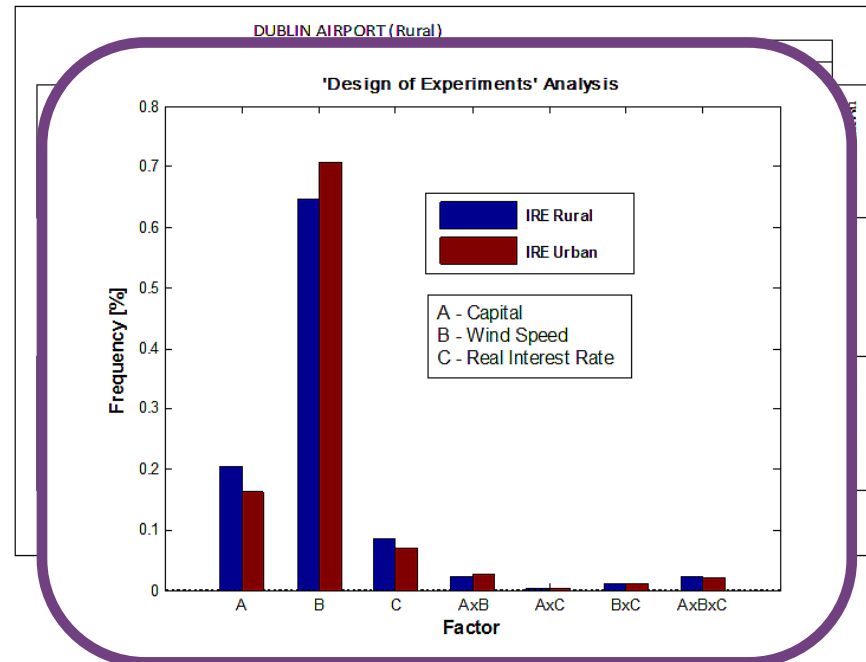
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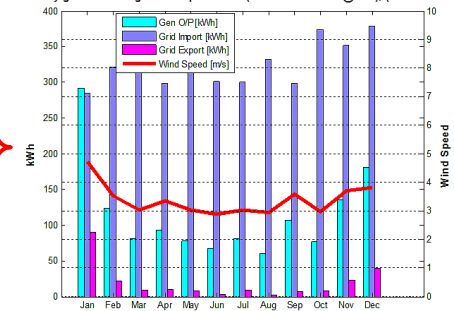
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Monthly generation & grid sales/purchases (u-mean of 3.4m/s @20m), (Urban Dublin)



Future work & Research Potential

Primary Resource

Demand Side

Software Interface &

Algorithm Development

- Wind energy resource extrapolation based on surface roughness modelling and boundary layer theory

Future work & Research Potential

Primary Resource

Demand Side

Software Interface &

Algorithm Development

- Network focus
 - EV integration
 - Network cabling & thermal considerations
- Demand-side
 - EV charging opportunities
 - Storage integration

Future work & Research Potential

Primary Resource

Demand Side

Software Interface &

Algorithm Development

- **Network focus**

- 
- EV integration **Consumers as 'prosumers'**
 - Network cabling & thermal considerations **Load/Gen aggregation & associated strategies**

- **Demand-side**

- EV charging opportunities
- Storage integration

Future work & Research Potential

Primary Resource

Demand Side

*Software Interface &
Algorithm Development*

- **OpenDSS** \leftrightarrow MATLAB development



THANK YOU!

ph.: +353-1-4024882

e: keith.sunderland@dit.ie