Impact of electric vehicles on the electric network and optimised charging strategy

Dr Alessandra Parisio
EEE School, The University of Manchester, Manchester, UK
email: alessandra.parisio@manchester.ac.uk

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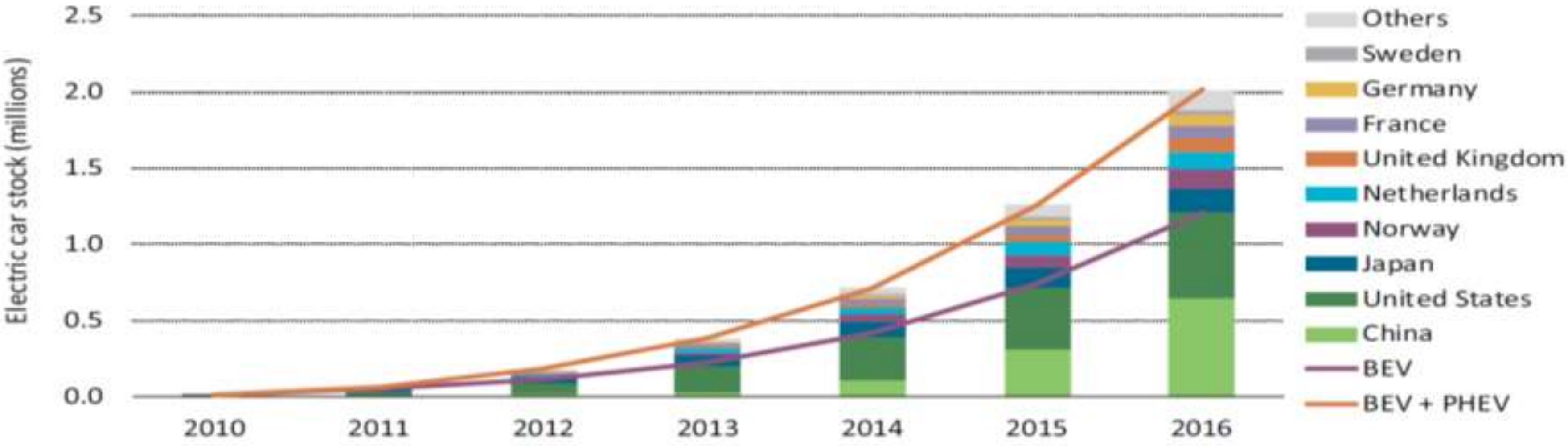
Motivation and context

- Air pollution and RES integration
- Italy is committed to deliver:
  - 80% CO_2 emission reduction in transport by 2050
  - 21% of its transport fuel from RES by 2030
- Increasing EV popularity
- Charging can cause grid-related issues

Evolution of the global electric car stock

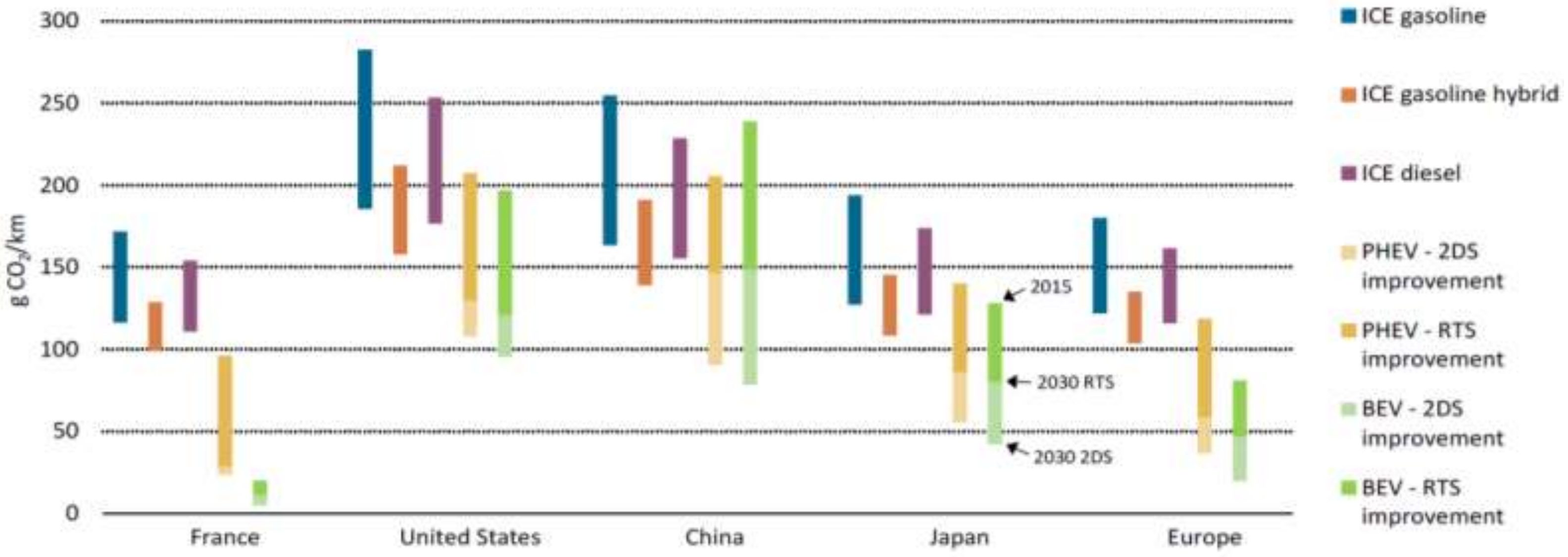
The electric car stock has been growing since 2010 and surpassed the 2 million-vehicle in 2016



Battery electric vehicle (BEV) uptake has been consistently ahead of the uptake of plug-in hybrid electric vehicles (PHEVs)

Emissions for technologies and countries

BEVs and PHEVs are already a lower-carbon option than ICEs and HEVs in less CO2-intensive grids (~200 g CO2/kWh)



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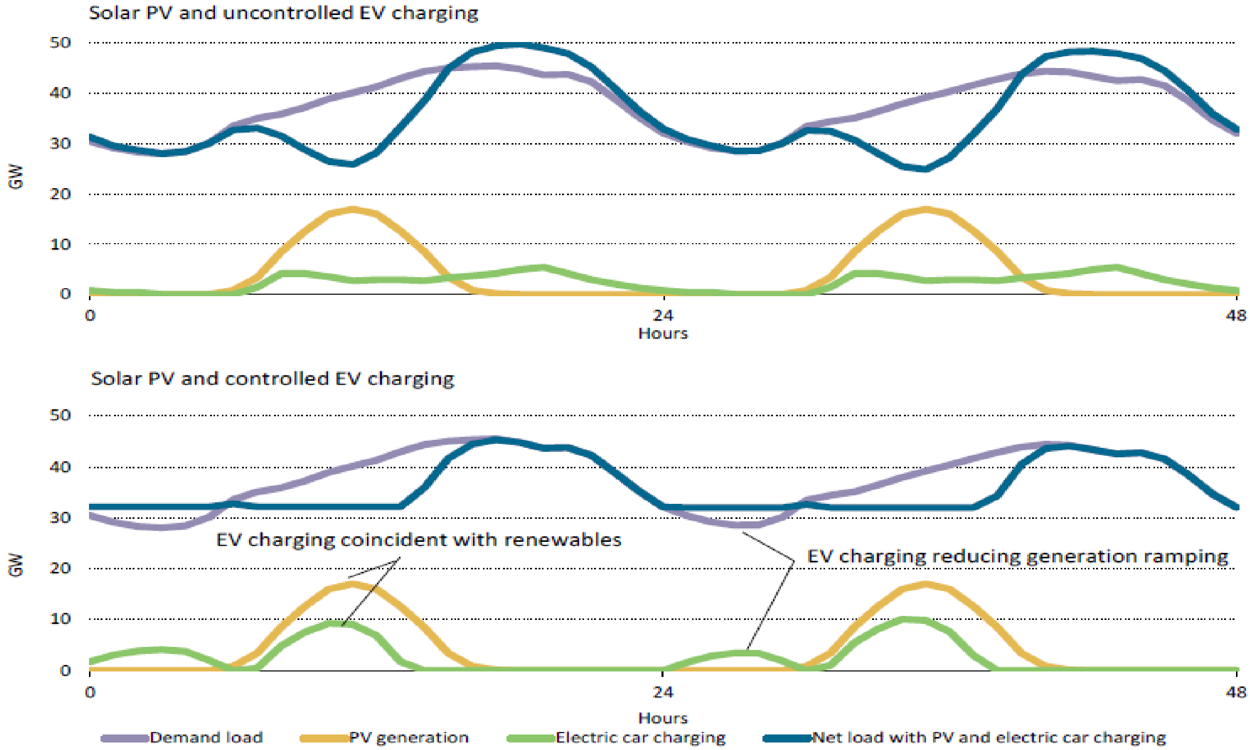
Impact at different levels

- At the generation/wholesale market level, high demand and scarce capacity could increase prices

- At the transmission/system operator level, stress on the system during peak times requires more system services

- At the distribution level, the overloading of power lines and transformers and voltage drops could occur

Local demand profile and electric car charging



Unmanaged charging would result in an increase in peak power draw of roughly one-third in 2030

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Regulate the charging process

- Charge all Evs on a radial distribution network as quickly as possible
- Minimise the impact on the network
- Allow consumers to reveal their charging rate preferences

Joint study with Kamal Qarain Silwani, The University of Manchester

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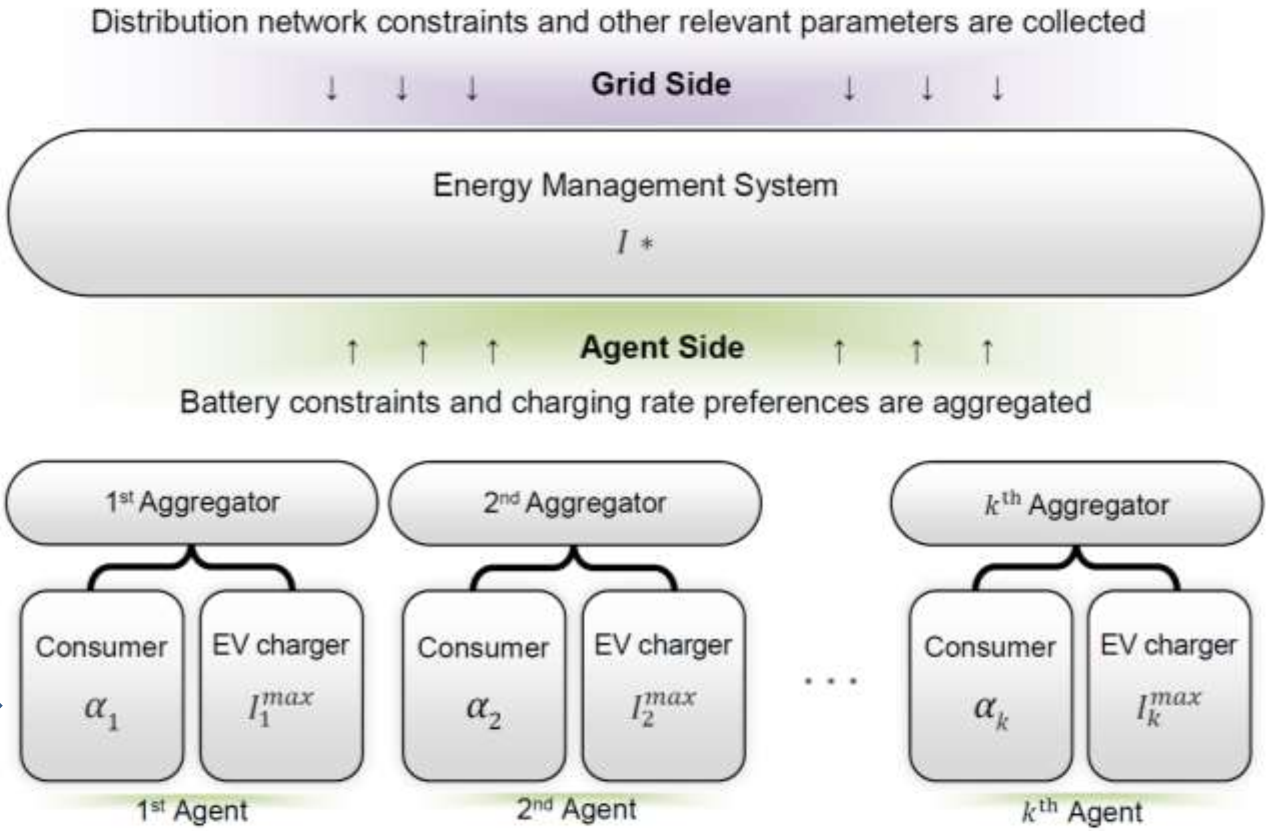
Communication architecture

- **Optimal charging rate is calculated**
- **Parameters are collected**
- **Consumers express preferences**

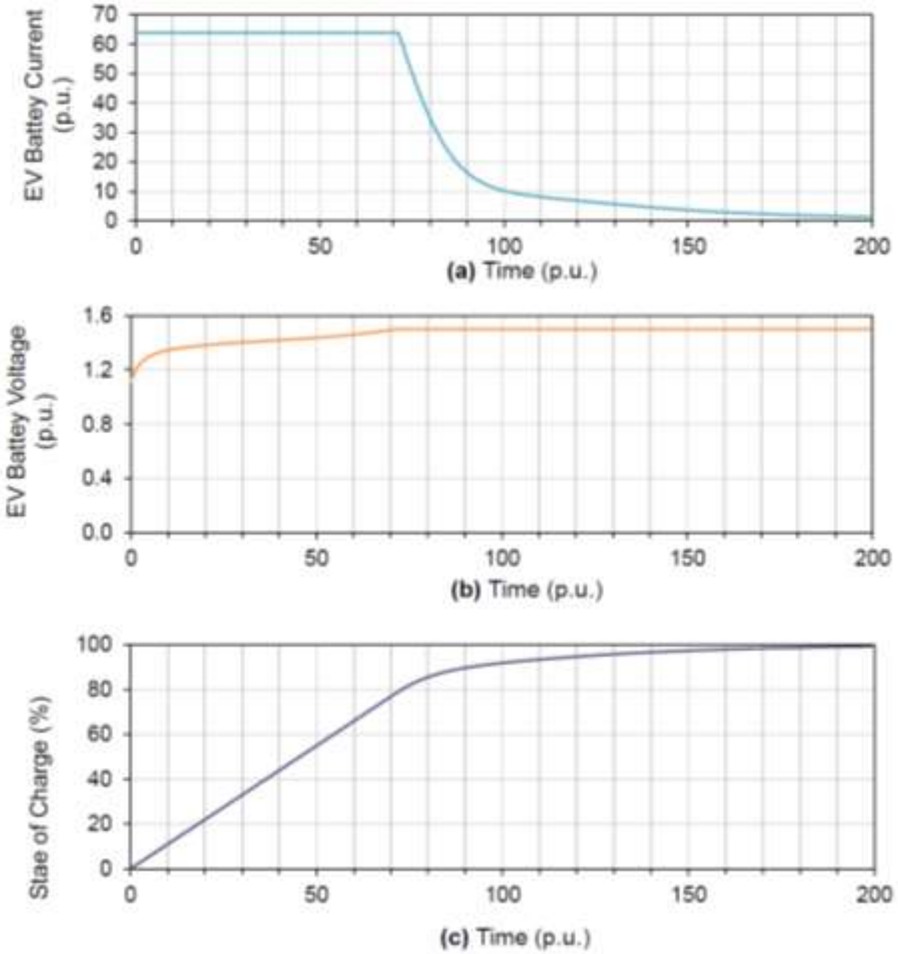


EV Agent

EV Battery Model: the charging dynamics of a Lithium Ion (Li-Ion) battery with a nominal voltage and a maximum rated charge capacity

Constant Current Constant Voltage (CCCV) charging Controller:

- *First Phase* - Constant Current (CC)
- *Second Phase* - Constant Voltage (CV)



Charging standard

Charger Mode	Single Phase		Three-Phase	
	Maximum Current (A)	Maximum Power (kW)	Maximum Current (A)	Maximum Power (kW)
Mode 1	16	3.7	16	11.0
Mode 2	32	7.4	32	22.0
Mode 3	63	14.5	63	43.5

International Electrotechnical Commission (IEC) 61851-1:2017 Standard for Electric Vehicle Conductive Charging Systems

Aggregator

Data collection

- Consumer’s Price tier – Payment plan relating to preferred charging rate
- EV Battery Parameters – Mainly maximum allowed charging current

Event triggering

- Start of charging – Trigged once data is collected
- End of charging – Triggered once current drops below its minimum

Energy pricing

- Calculate the length of each charging session
- Measure the amount of energy consumed by the EV
- Charge EV a sum of money in accordance with the agreed utility function

Energy management system

Optimization

Maximizes charging rate

subject to

Network constraints e.g., voltage drop constraint, voltage should not drop by over 3.5% at the receiving end

Battery constraints e.g., charging rate constraint, avoid over-current (damages battery and charging electronics), avoid under-current (false, repeated triggering of end of charging event)

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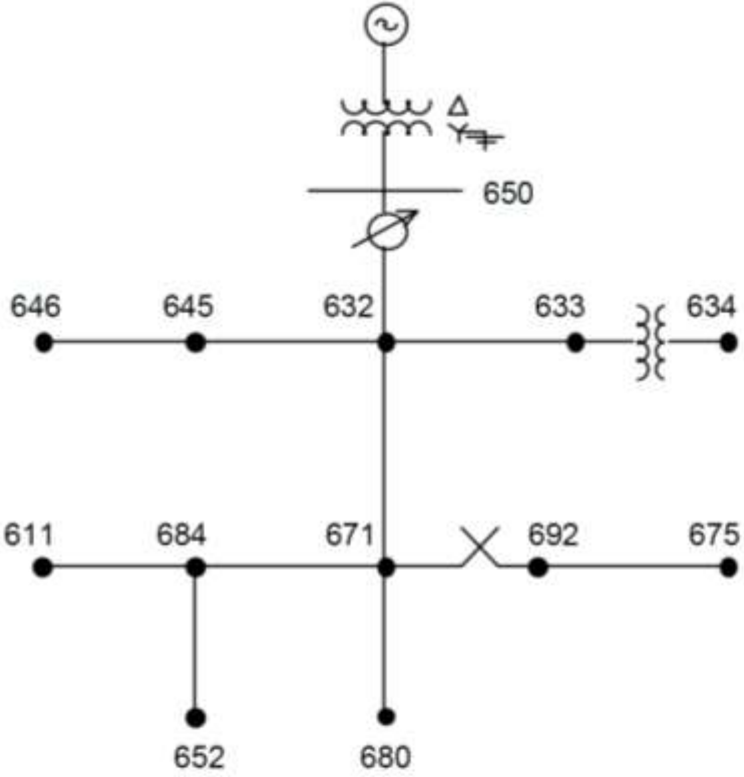
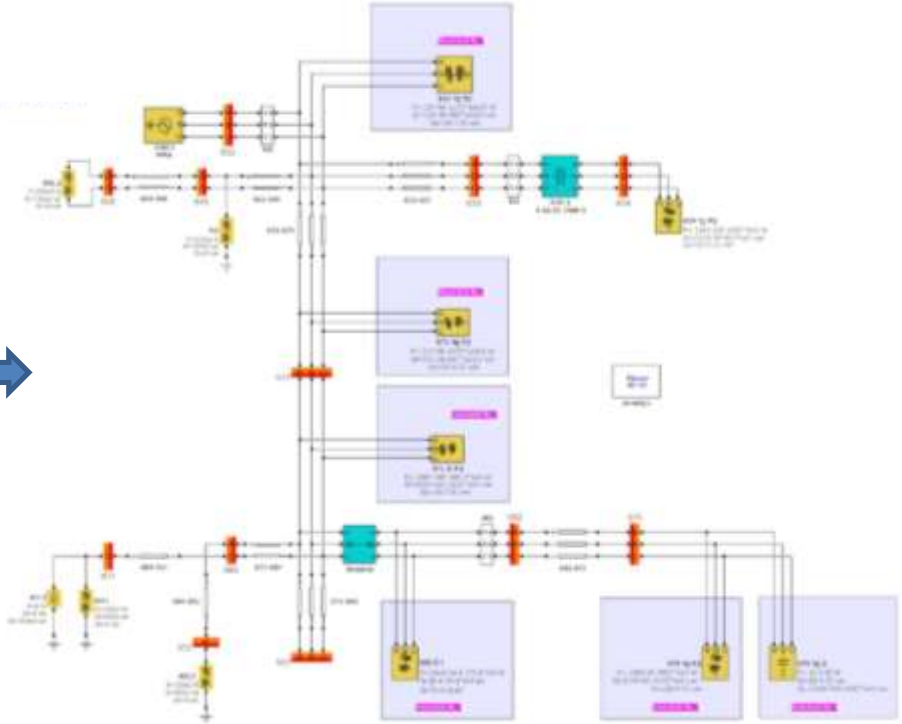
Benchmark test feeder



IEEE 13 Node Test Feeder



Test feeder in the Block-Diagram Programming Environment, Simulink

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EV penetration levels

● EV Charging -- No EV Connected

k	EV Penetration	n					
		1	2	3	4	5	6
2	Low	●	--	--	--	--	●
4	Medium	●	●	--	●	--	●
6	High	●	●	●	●	●	●

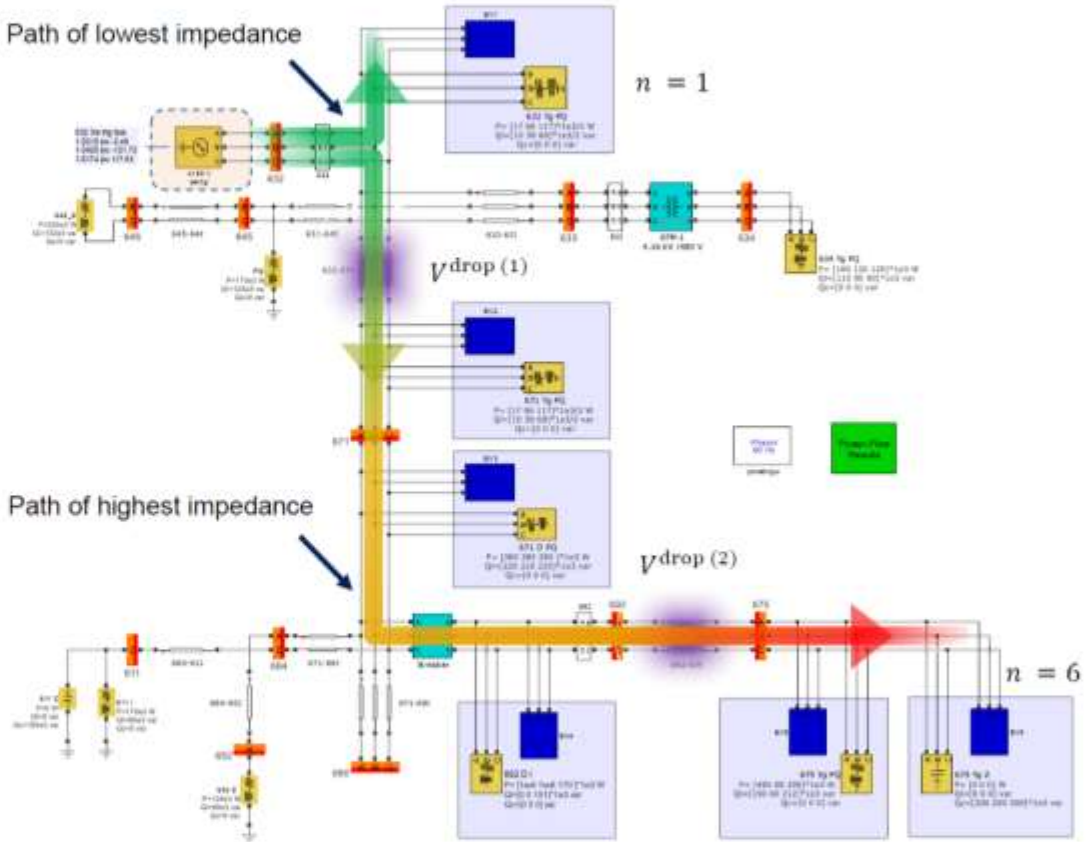
Variations in EV Penetration on the network

Summary of the of the IEEE Test Feeder Topology

(Colours correspond to voltage drops along the network, refer to the table below)

Parameter / Factor	Change Along the Network					
Consumer (n)	1	2	3	4	5	6
Bus ID	632	671		692	675	
Voltage Drop	$V^{\text{drop}\,(1)}$ ▲			$V^{\text{drop}\,(2)}$ ▲		
Distance from generator (d)	Increasing					

Transmission line voltage drops



Evaluation criteria

EV Charging Mechanism		EV Battery Constraints	Consumer Preferences	Network Constraints
A	'Dumb' Deregulated	Considered	None considered	None considered
B1	'Fair' Regulated	Considered	Price tiers, α, available	Voltage drop (Sets 'universal rule')
B2	'Unfair' Regulated	Considered	Price tiers, α, available	Voltage drop (Affects some parts)

For B1 and B2 all EV owning consumers were assumed to be on the high tier payment plan

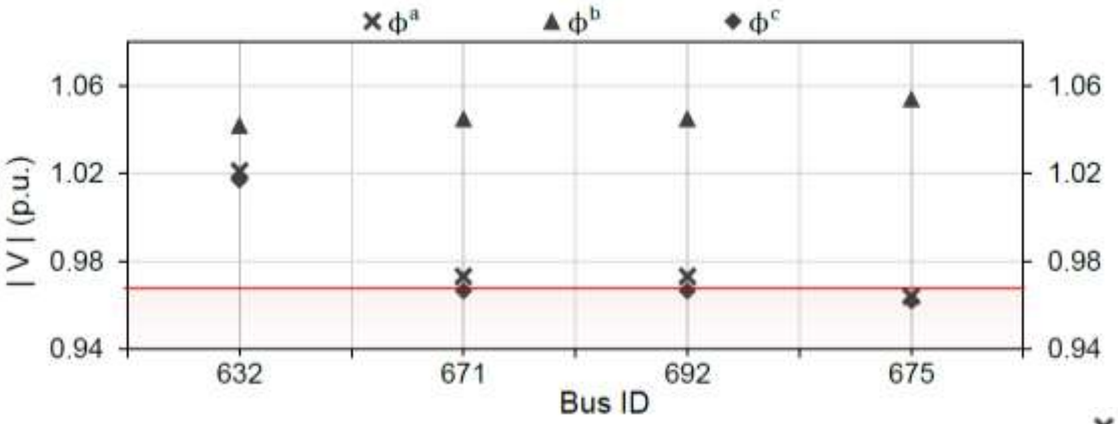
Results per EV penetration

- Mechanism A – 'Dumb' Deregulated Charging
- Mechanism B1 – 'Fair' Regulated Charging
- Mechanism B2 – 'Unfair' Regulated Charging

Mechanism - Penetration	Current	Length of the chargin session
A – Low, Medium, High	63 A	3 hours, 20 minutes
B1 - Low	38.571 A	6 hours, 45 minutes
B1 - Medium	38.571 A	6 hours, 45 minutes
B1 - High	16.1517 A	19 hours, 45 minutes
B2	Consumer 1: 63 A Others as in B1	Consumer 1: 3 hours, 20 minutes Others as in B1

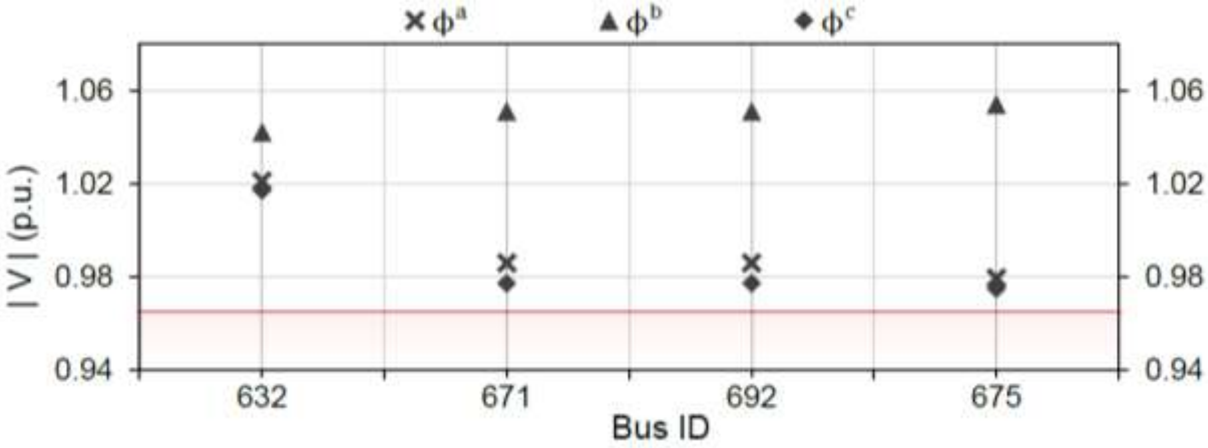
Deregulated vs regulated: voltage

High EV penetration



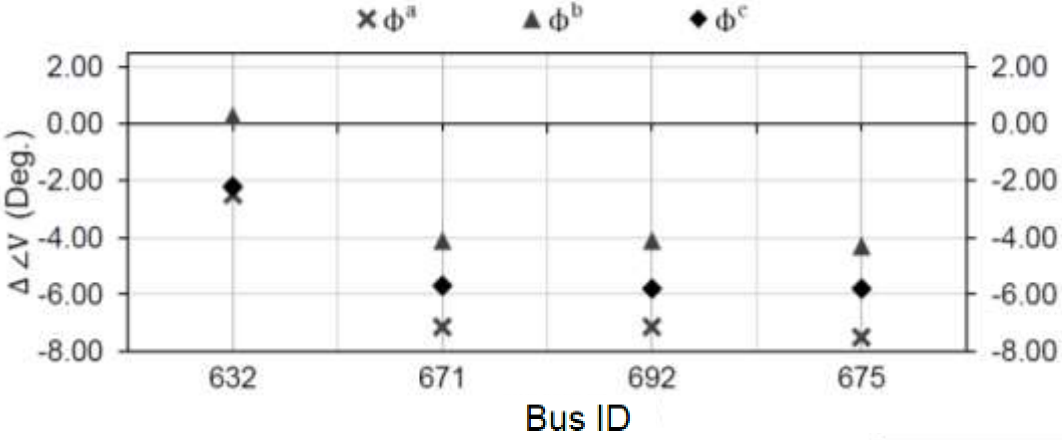
Deregulated

Regulated



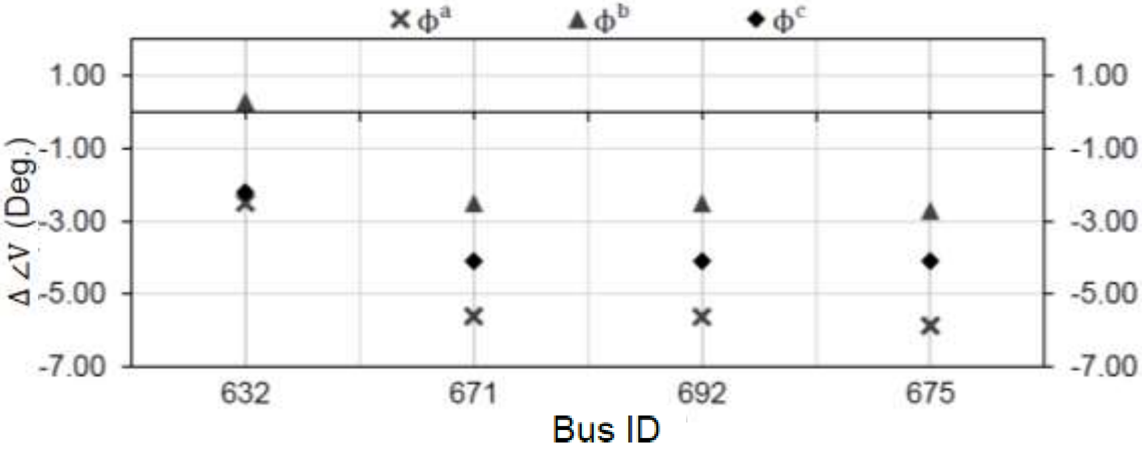
Deregulated vs regulated: phase

High EV penetration



Deregulated

Regulated



In conclusion

✔ Respects consumer preferences – price tiers introduced

✔ Aware of the network topology – network constraints met

However…

 Slow charging in high EV penetration scenarios – vehicle to grid and RES coupling

 Bottleneck introduced if 'Fairness' is enforced

Mitigating the impact

- Install charging points in areas where the projected impact is low
- Incentivise end users to maximise self-consumption through solar systems installed on consumers' homes
- Delay charging of large numbers of ICT-enabled charging points
- Charging profiles set by the DSO, which could in turn provide increased hosting capacity to service providers

Thank you