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Smart EV Charging and Battery Optimization to Support the Smart Grid

London

Friday 11th April 2014

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Acknowledgement
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Agenda

- Introduction
- The Need for Smart Charging
- Battery State of Health
- Impacts of EVs on the Grid
- Smart Charge Controller
- Results
- Summary

Charging Options

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	Home charging	Public charging	Fast charging
Power	3 or 7 kW	23 kW	Up to 50 kW
Time	8 or 4 hours	1 hour	20 mins (80%SOC)
Average C-Rate	0.12 or 0.25 C	1 C	3 C

Existing chargers provide limited controllability (e.g. charging specifications) and flexibility to the user (e.g. charging time and length of next journey).

That is: they are not smart !

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The Need for Smart Charging

- User requirements
- Battery State of Health
  - This is very sensitive to the charging/discharging regimes
- Grid Impacts
  - EV batteries have high energy/power density
  - Charging can have negative impacts on the grid but also provide opportunities.
- Charging from renewable energy resources
  - EVs are not green unless charged from renewable sources

User Requirements

- Charge at home, work, street or fast charging
- Most users charge daily at home
- Most journeys are relatively short (well below the maximum range of the EV)
- Most EVs are used for relatively short periods during the day.
- Range anxiety
- The EV user requirements are defined in terms of the next journey length and the time the user is willing to wait for charging to complete.
- Charging only the necessary amount of energy required for the next journey can help the battery SOH and extend its life.

Battery State of Health (SOH)

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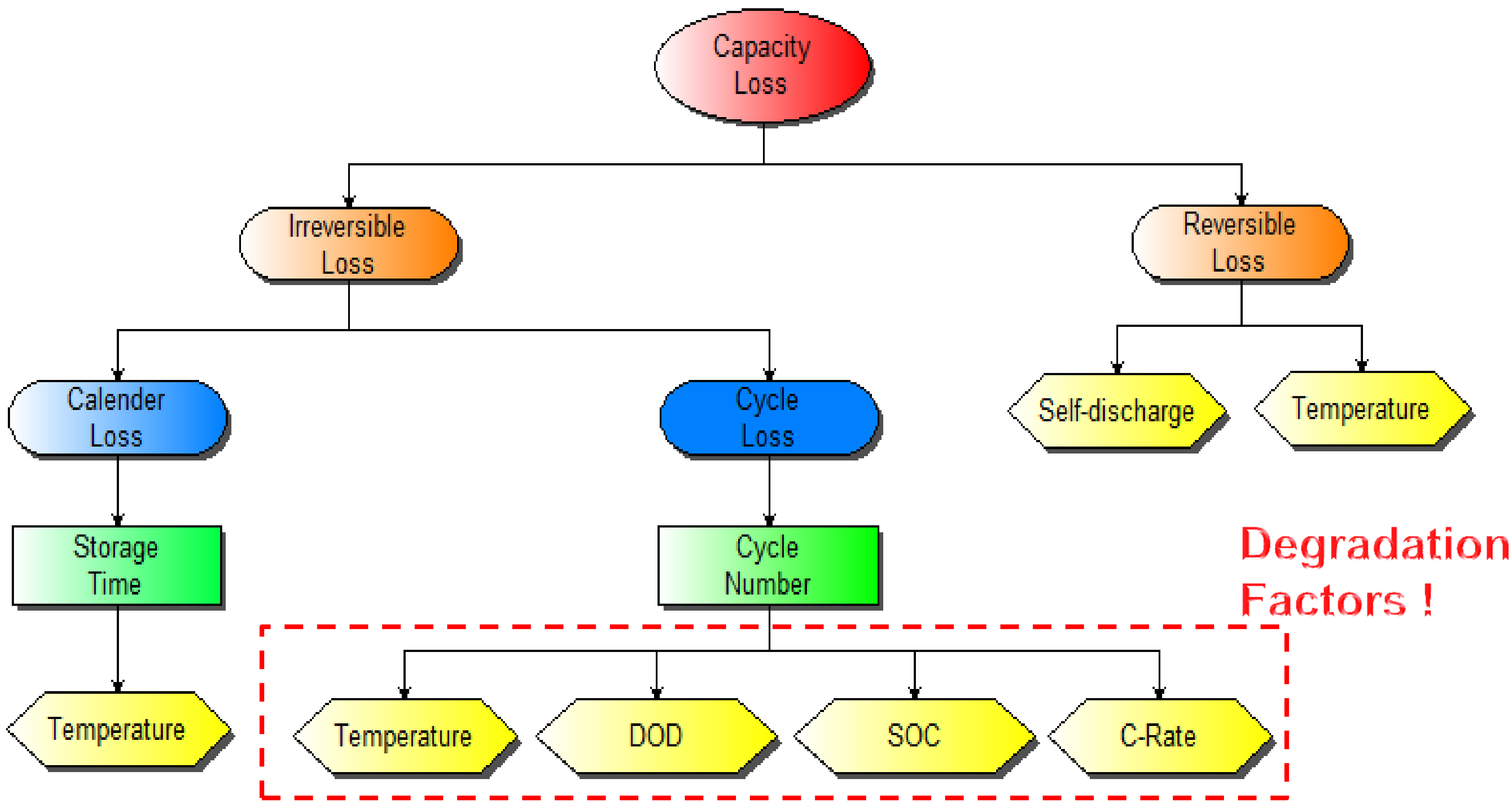

EV (Li ion) battery degradation (aging)

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Effect of Temp. on Battery SOH

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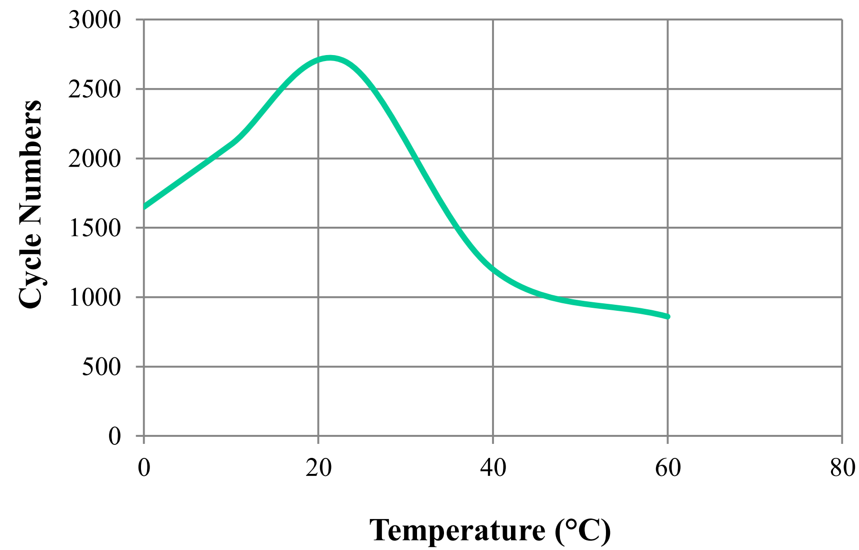
PERMANENT CAPACITY LOSS VS. STORAGE CONDITIONS

Storage Temperature	40% Charge	100% Charge
0°C (32 °F)	2% loss after 1 year	6% loss after 1 year
25°C (77 °F)	4% loss after 1 year	20% loss after 1 year
40°C (104 °F)	15% loss after 1 year	35% loss after 1 year
60°C (140 °F)	25% loss after 1 year	40% loss after 3 months

http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

Effect of temperature on calendar loss



Effect of temperature on cycle life

- Permanent capacity loss (ageing) increases with temperature.
- EV batteries are designed to operate at an ambient temperature between -10°C and 40°C. However, during cycling, battery SOH is best at room temperature (around 20°C).

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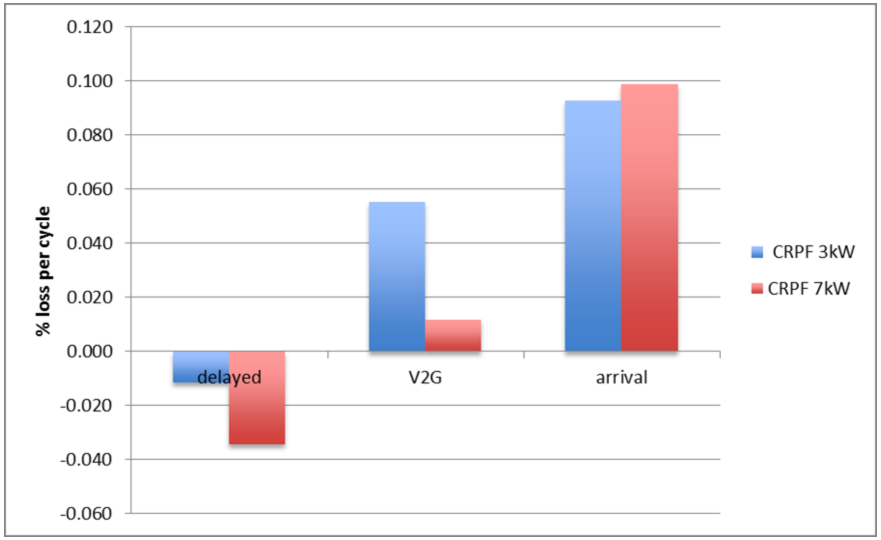
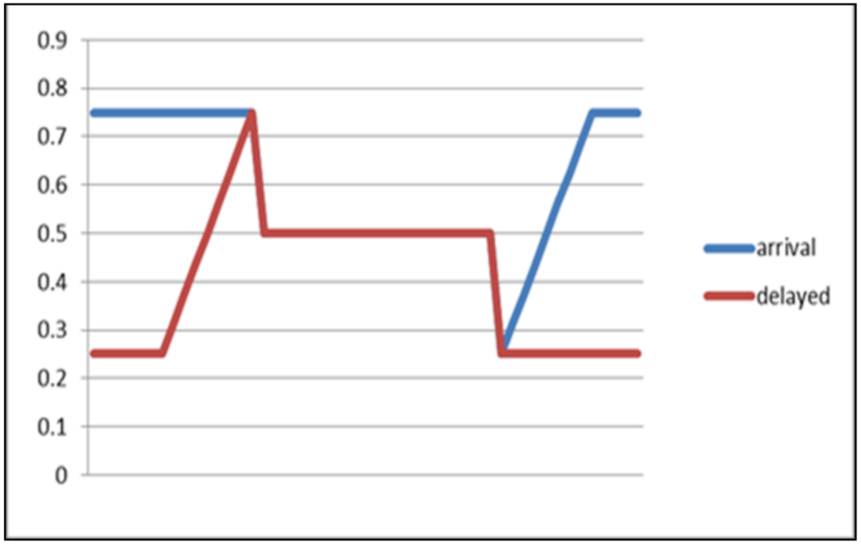
Effect of Average SOC on Battery SOH

- Test results verify the literature, that low average SOC reduces capacity loss and thus increases battery life
- This can be achieved by delaying charging until required for next use
- Smart charging will lower average SOC



Based on 4 ‘Enix’ Li-ion cells, capacity 6.8Ah cycled on a daily basis between 25 and 75% SOC for 100 cycles.

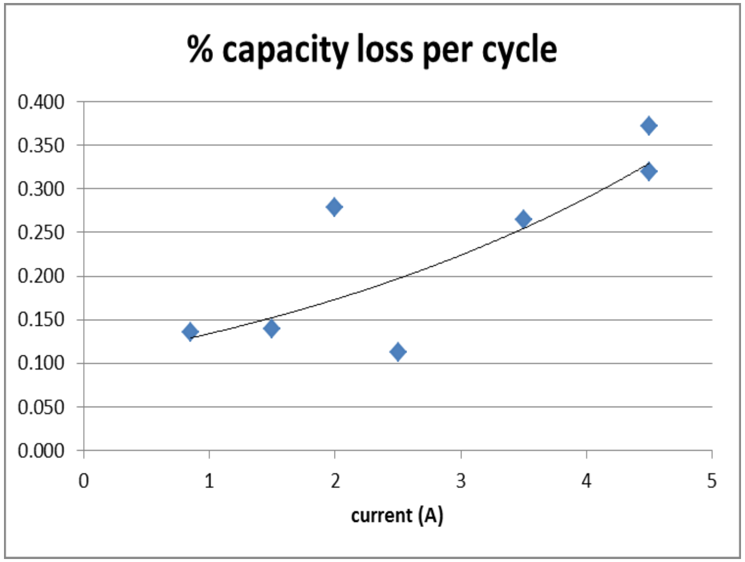


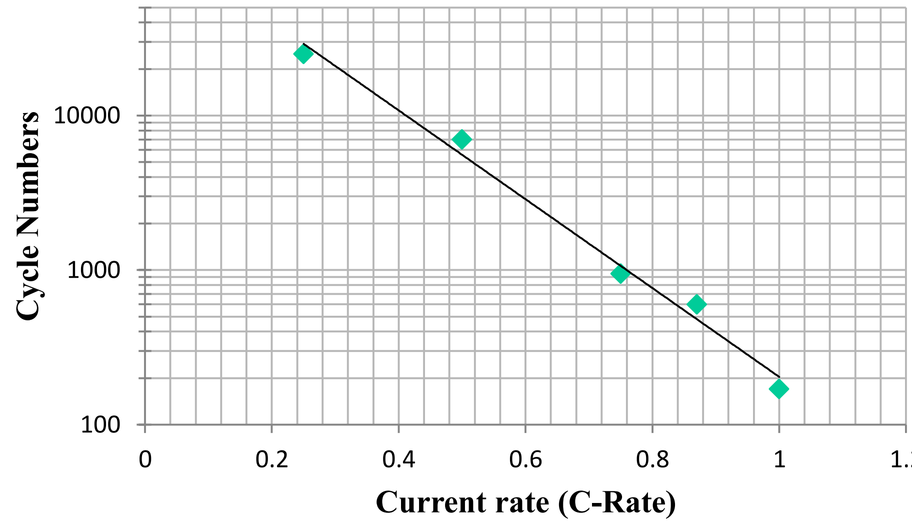
Smart charging can lower average SOC

Battery SOH is best at low average SOC

Effect of Charge/Discharge Rate on Battery SOH

Tests at different charge rate show some variation but the trend is clear





kW equivalent charging rate	% capacity loss / cycle
3	0.013
7	0.028
23	0.3200

These cells are not designed to run at 1C so results for 23kW is not typical.

	Change in internal resistance (over 100 cycles)	Change in capacity (over 100 cycles)
1 C cycling	4.5%	1.4%
2 C cycling	4.4%	2.6%

Different cells with 2C capability show increased ageing with rapid charging

Battery SOH is best at low charging/discharging current

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Effect of DOD or Change in SOC on Battery SOH

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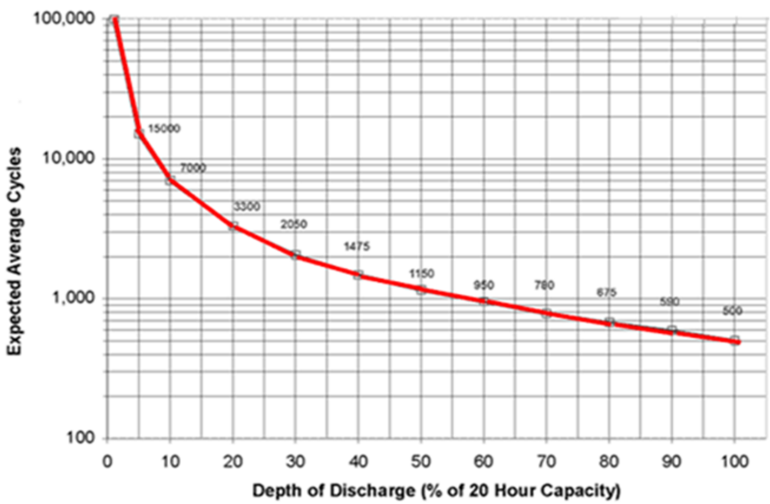
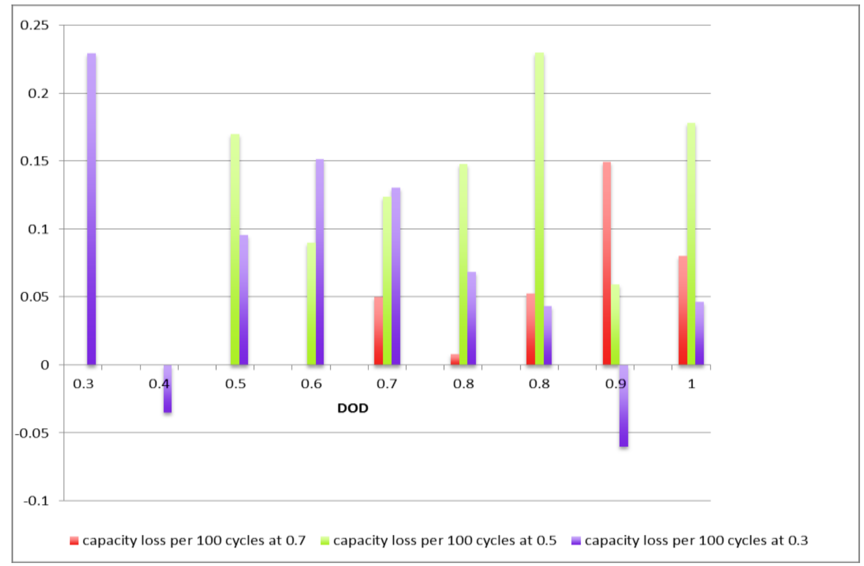
Capacity decreases with depth of discharge



The graph is for a Lead acid battery, but is typical for all cell chemistries including Lithium-ion. Battery life depends on the total energy throughput that the active chemicals can tolerate. Ignoring other ageing effects, the total energy throughput is fixed so that one cycle of 100% DOD is roughly equivalent to 10 cycles at 10% DOD and 100 cycles at 1% DOD.

Results appear to show that the effect of DOD is not statistically significant



It is unclear whether DOD is the same as change in SOC as published results always use 100% SOC as the max value

Battery SOH is best at low DOD

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Smart Charging can prolong the life of the battery

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- Keep battery temp around 20°C
  - Ensure BMS keeps cells temperature within range
  - Avoid fast charging/discharging, especially when ambient temp is high
- Keep average SOC low
  - Minimise charging as much as practically possible. Charge before next use (smart charging).
  - V2G can be used to minimise average SOC!
- Keep DOD low
  - Allow low charge/discharge several times rather than full recharging/discharging
- Keep charging rate low
  - Charge at the lowest convenient current rate whenever possible

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Impacts of EVs on the Grid

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- Uncontrolled loading due to increased deployment and potential increase in peak demand
  - EVs have high energy capacity and mass deployment
  - Charging demand to be met in car parks
  - Dealing with uncontrolled ‘mobile’ loads
  - Seasonal ‘migrations’ of demand
- EV as part of the Smart Grid
  - Plug-in and charge the battery at will or when the price is right
  - Provide ‘energy storage’ for supply/demand matching
  - Provide ancillary services and network support, e.g. voltage and frequency control
  - Charge EVs from available generation from renewable energy
- Need smart grid interface controllers

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Impacts of Large Deployment of EVs

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- Meeting energy requirements of EVs from available grid capacity
  - A study has shown that the UK national power grid is adequate for up to 10% market penetration of EVs. This is based on available generation and aggregate network capacity.
- The following need to be appropriately assessed:
  - **Uncontrolled loading at distribution level due to increased deployment of EVs and potential increase in peak demand**
  - **Change in voltage profiles and violation of statutory limits**
  - Phase imbalance (specific to 1-ph interface devices)
  - Reverse power flow (V2G)
  - Interference with network protection (EV interface devices may be designed to minimize/eliminate this).

System Analysis

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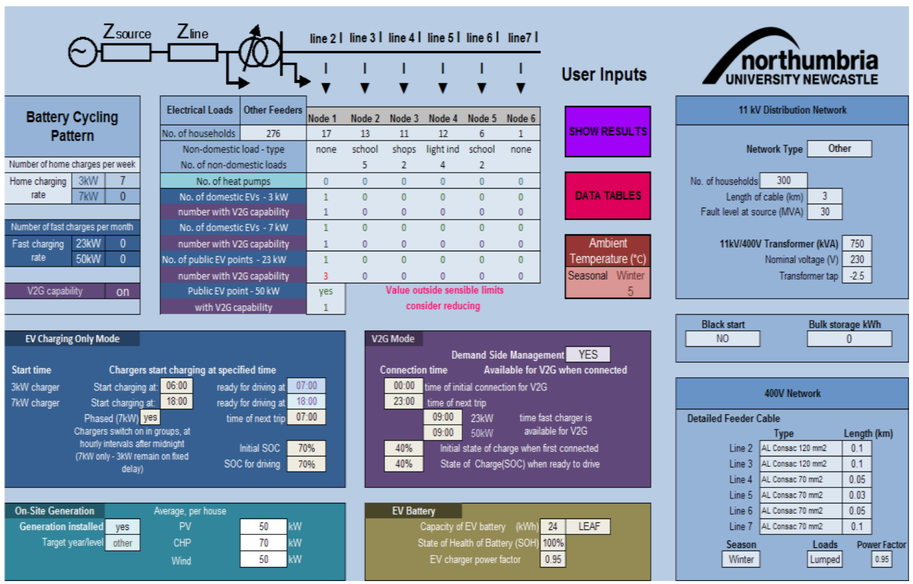
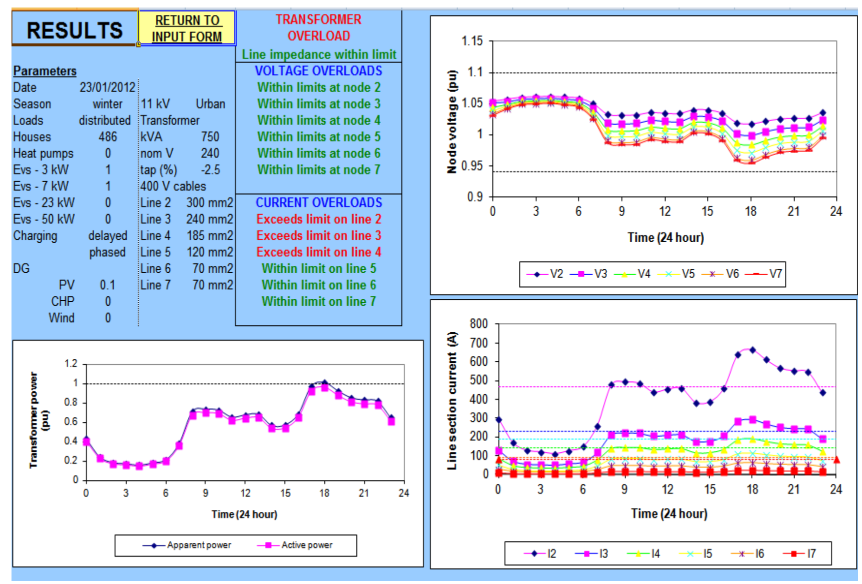
A computer model was developed to simulate a typical LV network and show how the power flow and voltage vary though a 24 hour period with and without EVs, renewable energy sources, battery energy storage, heat pumps, etc.

The model allows evaluation of the impacts of EV charging posts and analysis of smart grids solutions, G2V, V2G, smart charging and the impact of battery cycling on the battery state of health.





The modelling tool was developed as part of a project funded by Charge Your Car North (Electric Vehicle Infrastructure – Smart Grids and EV Infrastructure Regional Impact).

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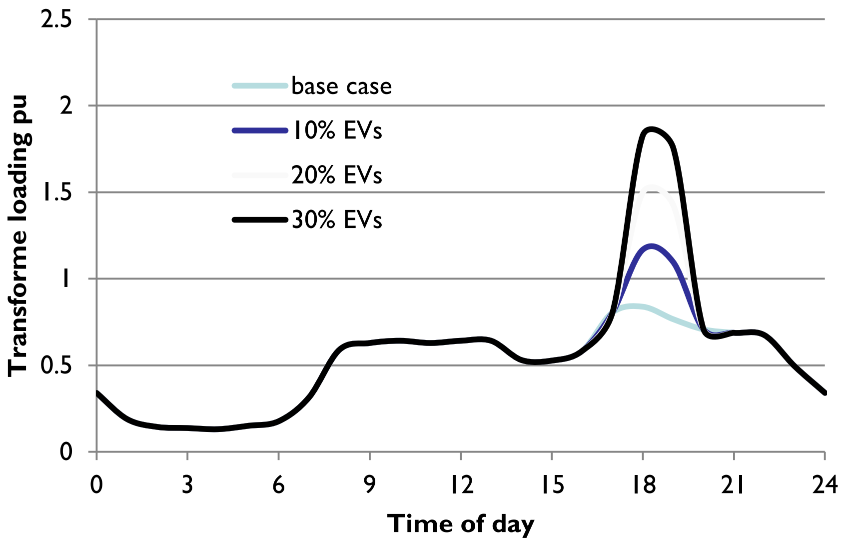
EV charging on arrival in Winter (uncontrolled)



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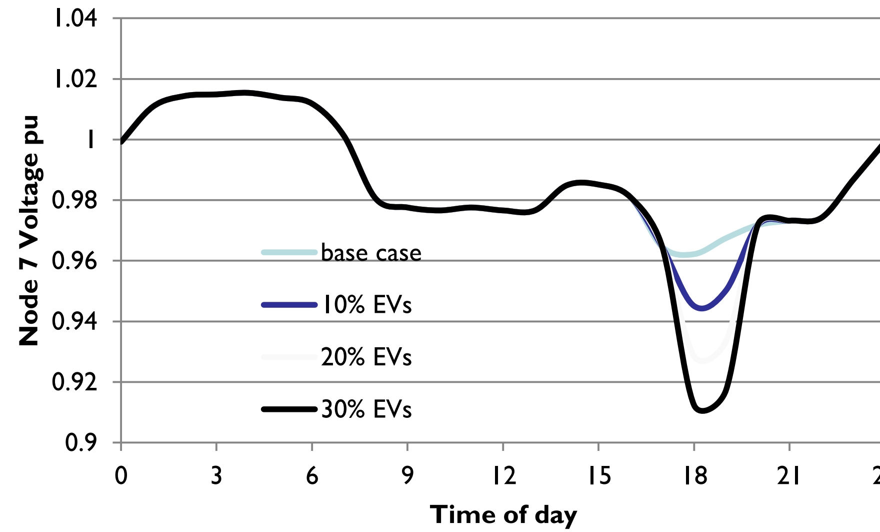


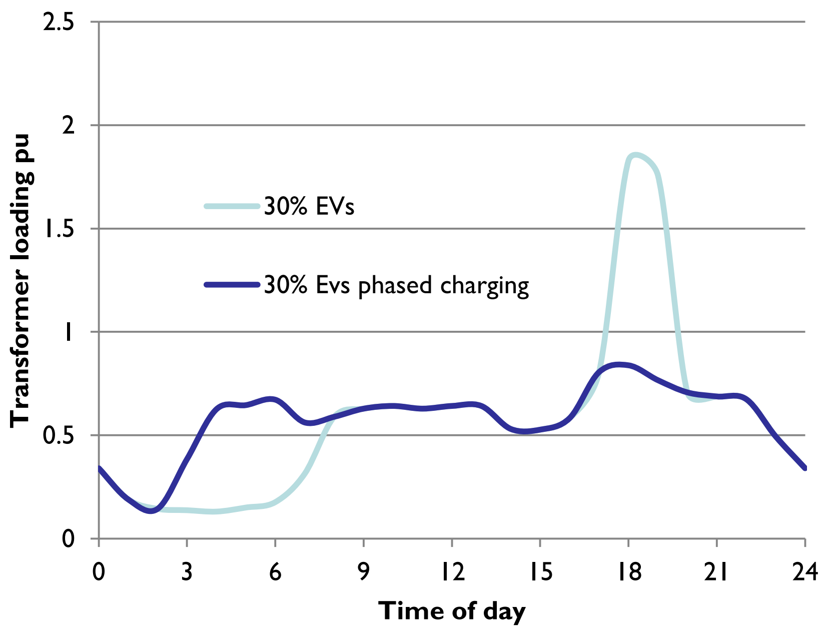
End of line voltages

Increase of ~18% loading for every 10% increase in houses with EVs

EVs at 20%: Operation of the OLTC keeps the voltage within the statutory limit.

EVs at 30%: The OLTC reaches its maximum limit and voltage levels at some points drop below the limit.

30% EVs with phased charging to avoid overload and excessive voltage drops



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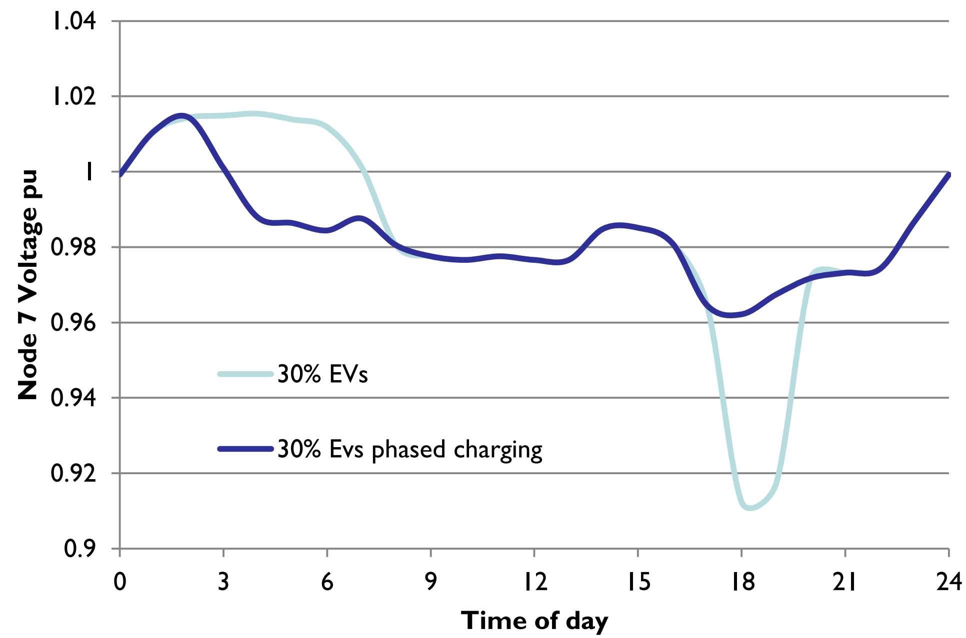
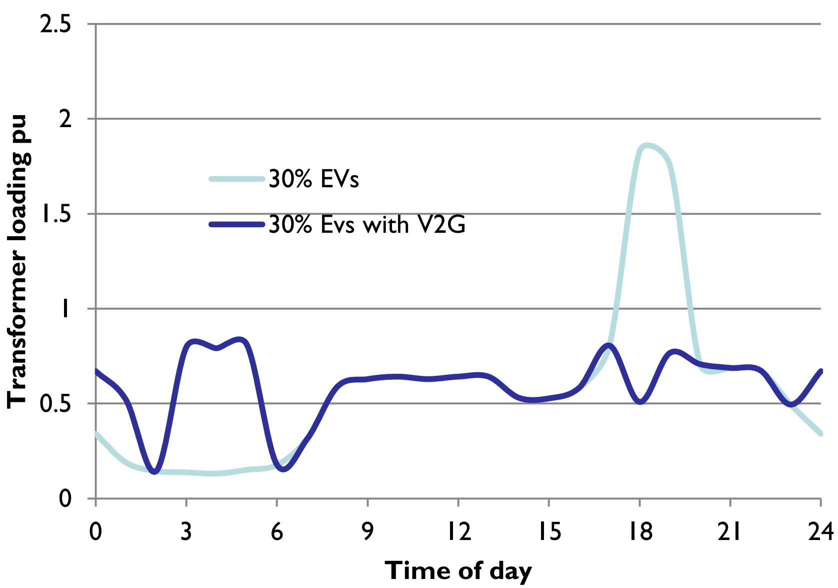


End of line voltages

‘Smart’ charging, e.g. by using incentives for customers, will reduce daily variations and improve load factor (match network capacity)

30% EVs with V2G to avoid overload and excessive voltage drops



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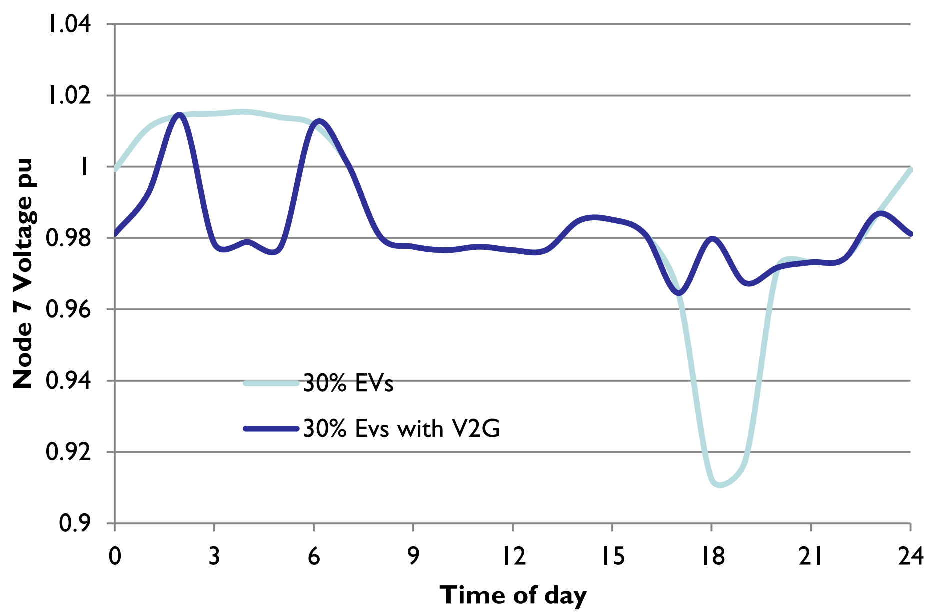
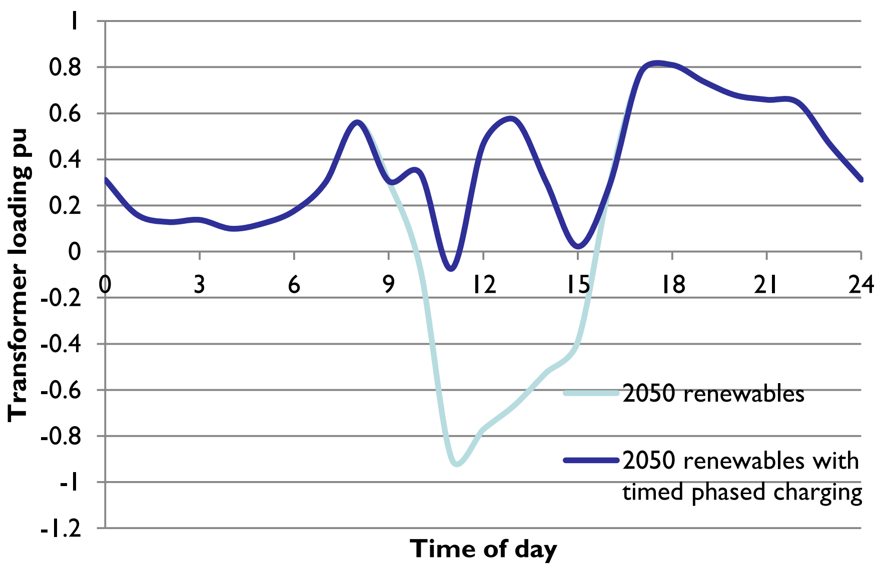
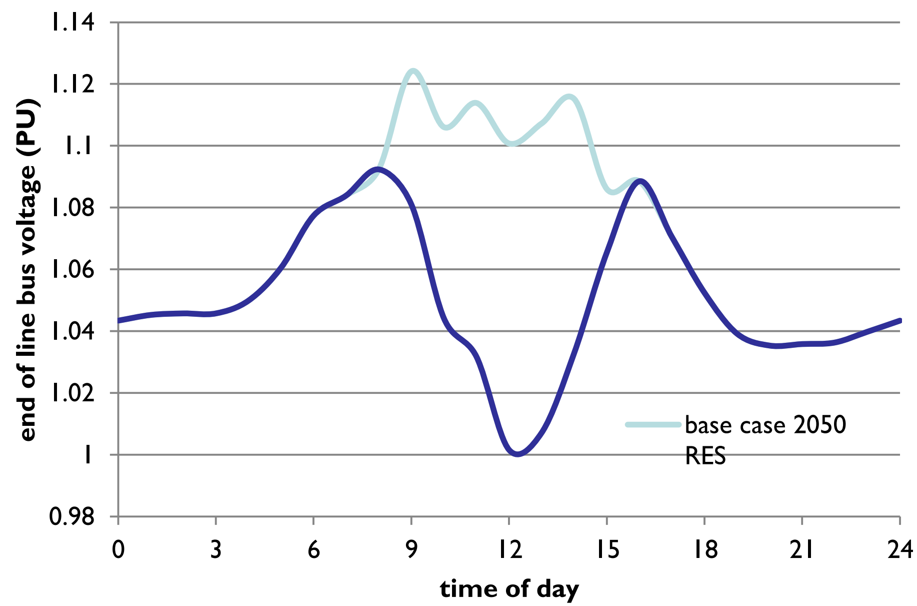


End of line voltages

2050 level of renewables in Winter and Summer



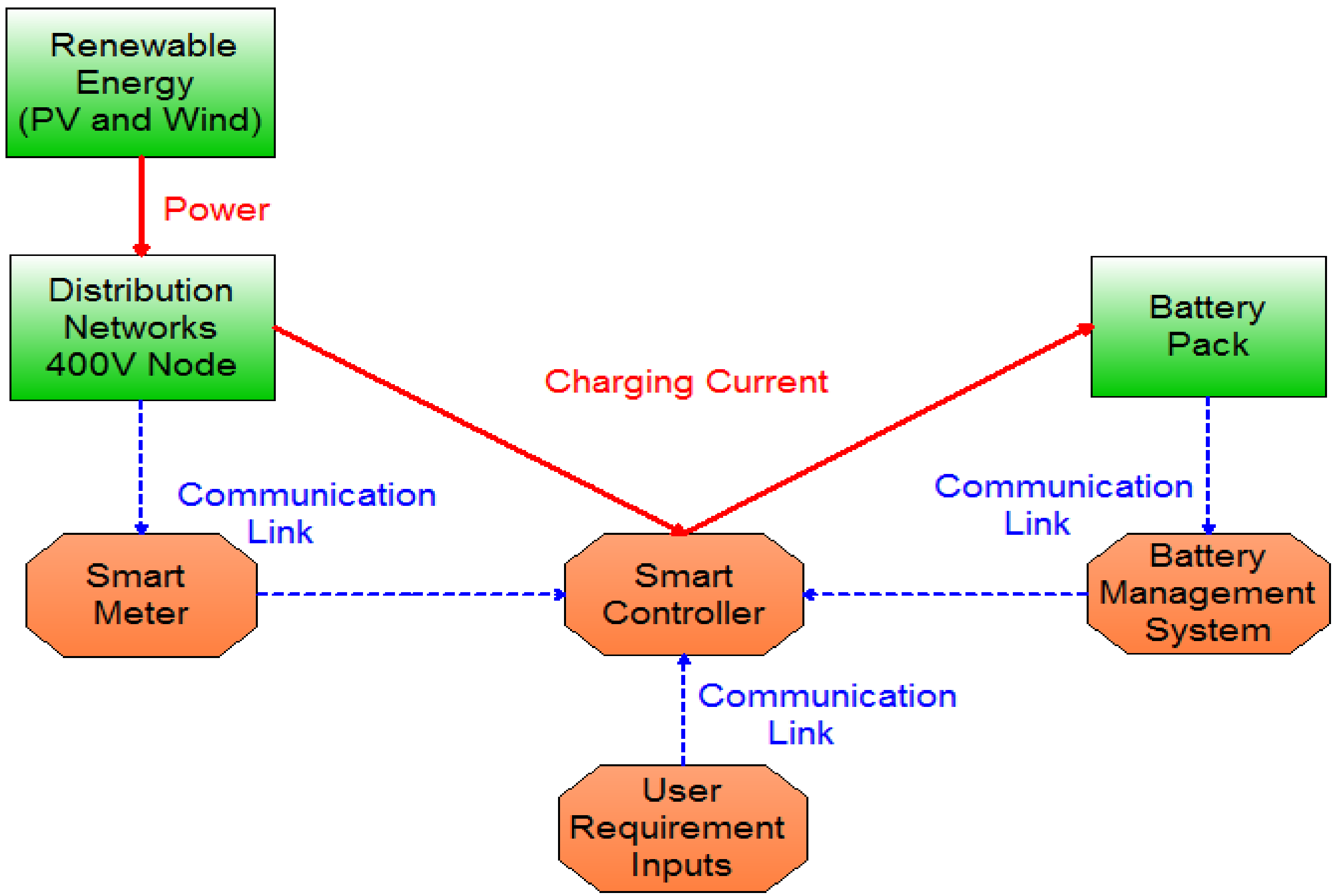
Transformer Loading
50% EVs in winter with phased charging to avoid reverse power flow



End of line voltages
90% EVs in summer with G2V to avoid over-voltages

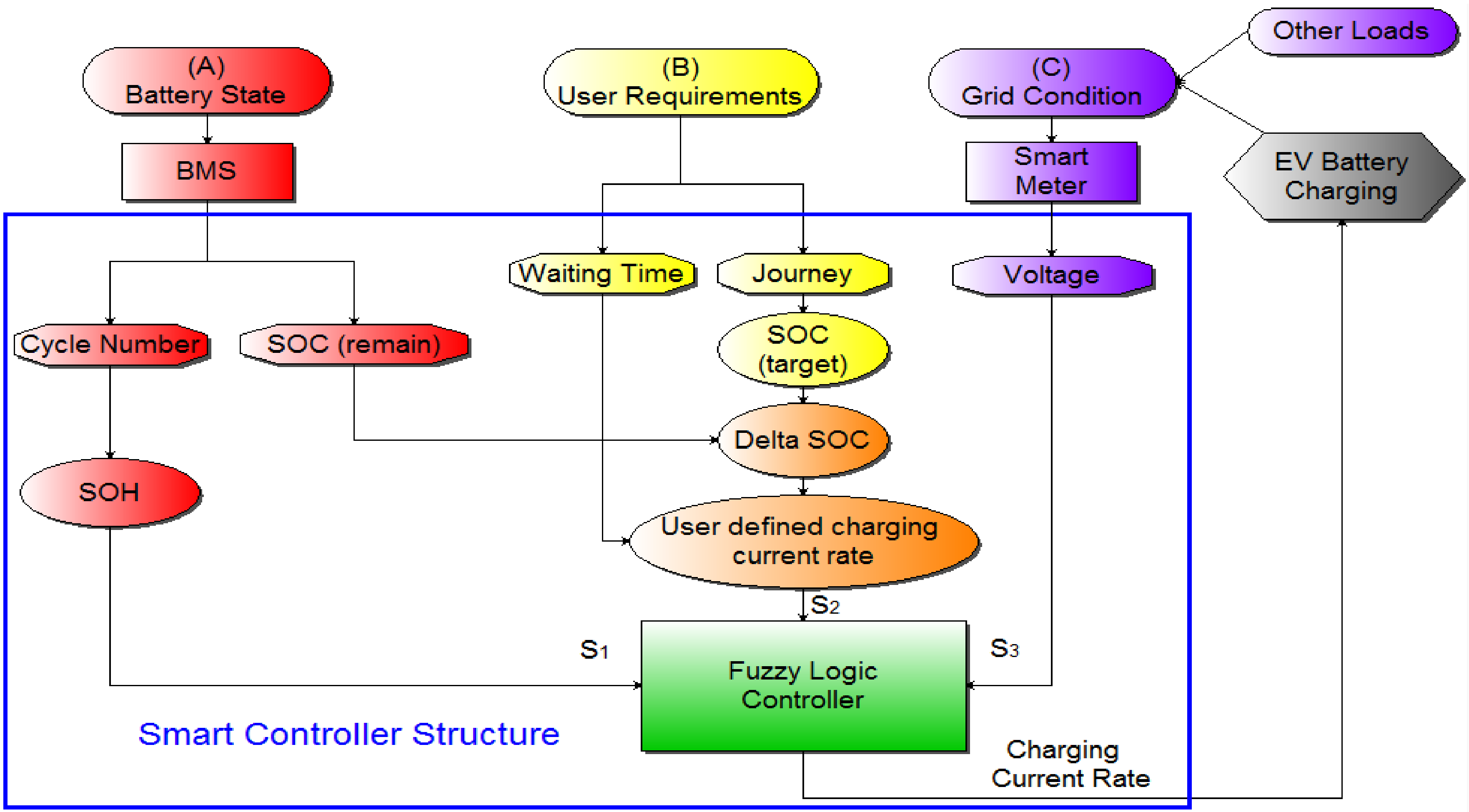
'Smart' charging will improve the quality of supply, support integration of renewable energy sources and charge EVs from renewable energy (zero carbon EVs)

Smart Charging



The Smart Charge Controller

The smart controller determines the optimal charging current by considering the network condition, the battery's state of health (based on information from the battery management system), and user requirements (journey length and charging waiting time).



Smart Charging Rules

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- Charge the battery to user specifications, as long as there are no restrictions from the grid or the battery SOH.
- Monitor the grid condition (voltage and thermal limits) and adjust the battery charging current (if needed), in proportion to the deviation from the nominal (rated) limits.
- Monitor the battery SOH and adjust the battery charging current (if needed) in order to avoid negative impacts on the battery cycle life.
- The priority of each input can be set (weighted) depending on the design requirements, where the battery is charged based on user requirements and battery SOH unless it conflicts with other factors.

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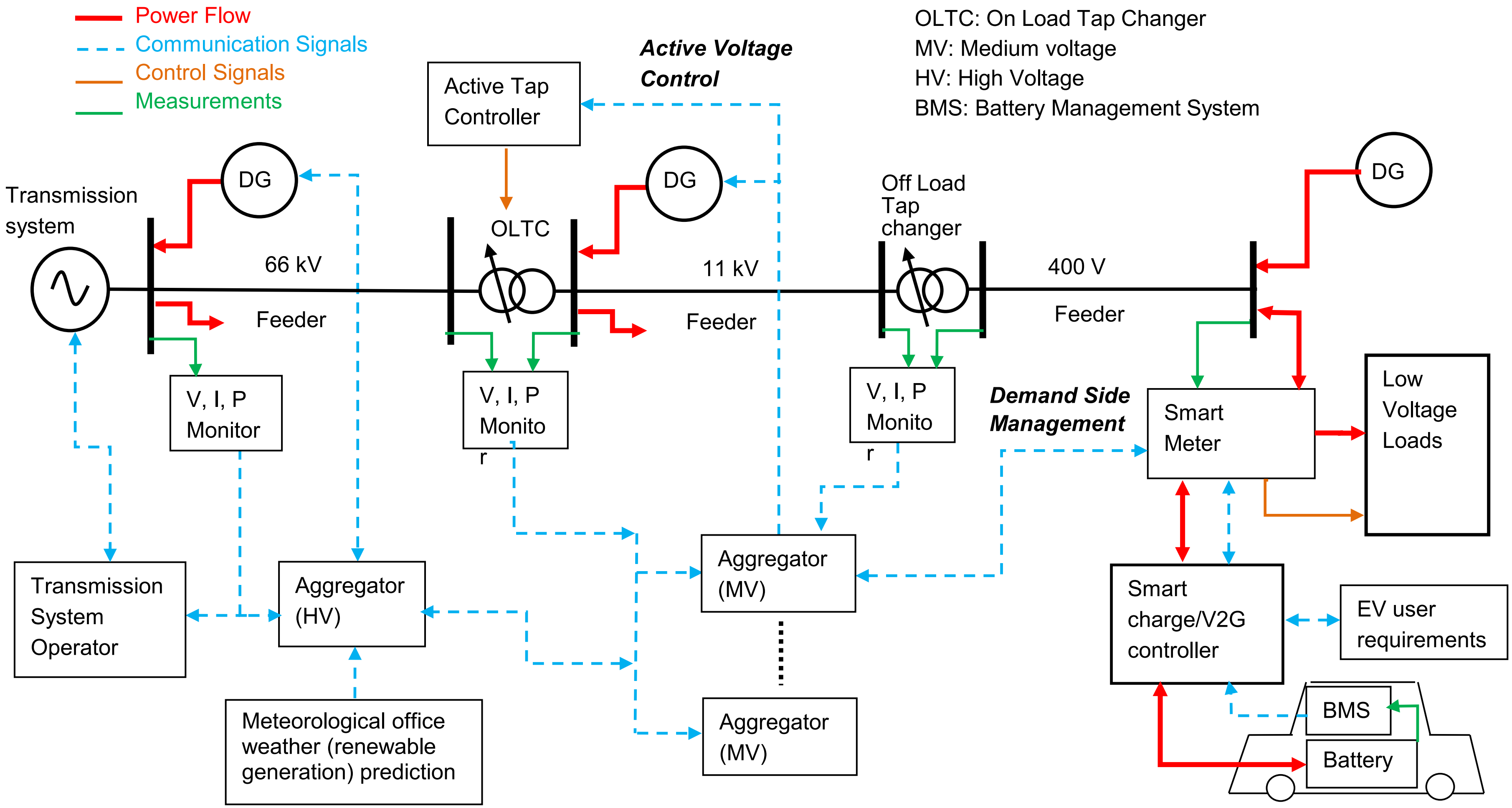
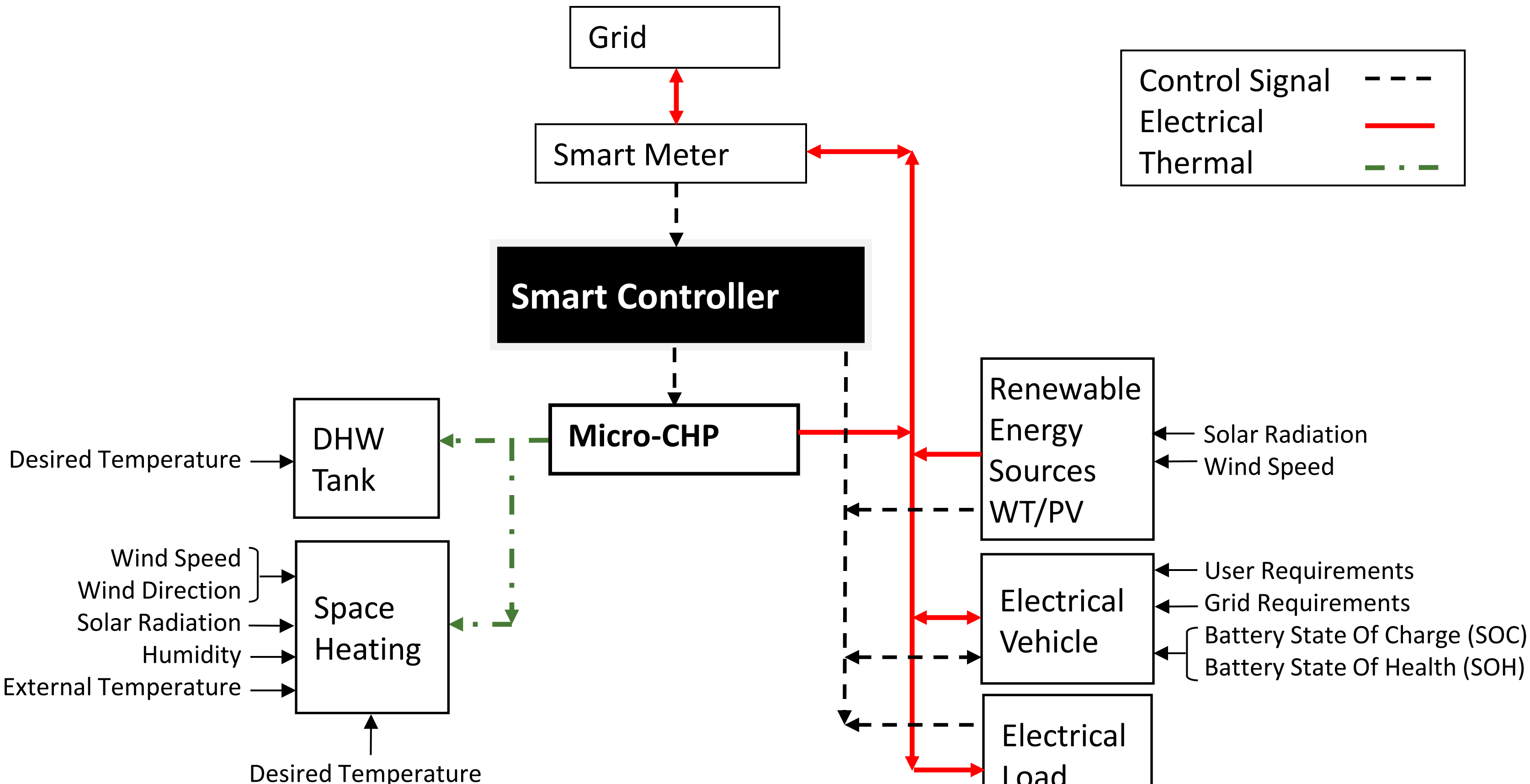
Smart Distribution Network

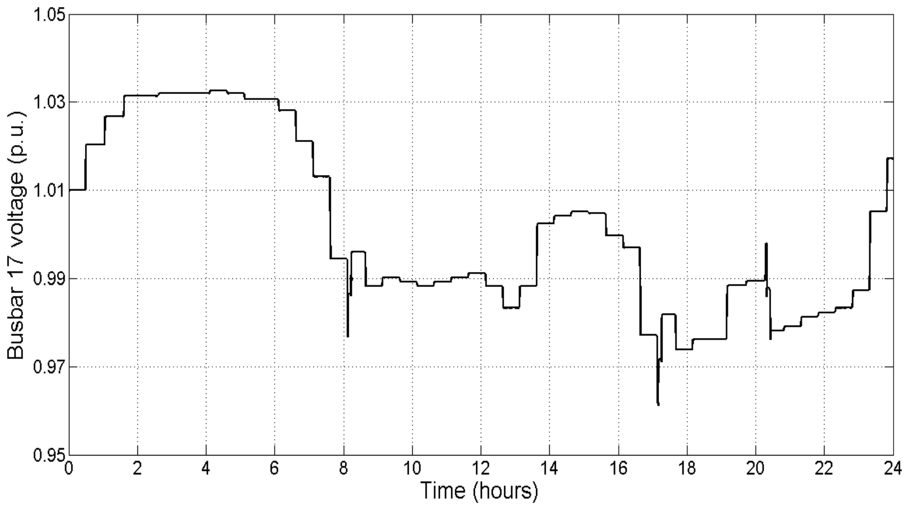


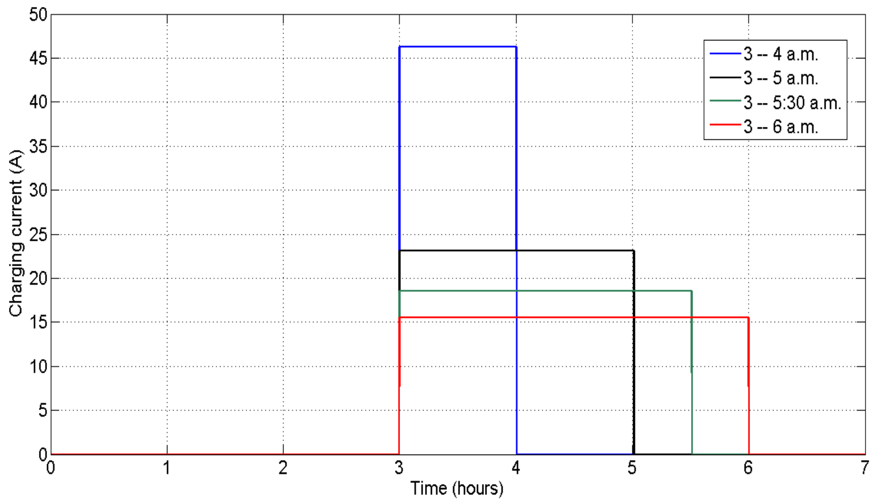
A Smart controller for Dynamic Energy Management in the Built Environment



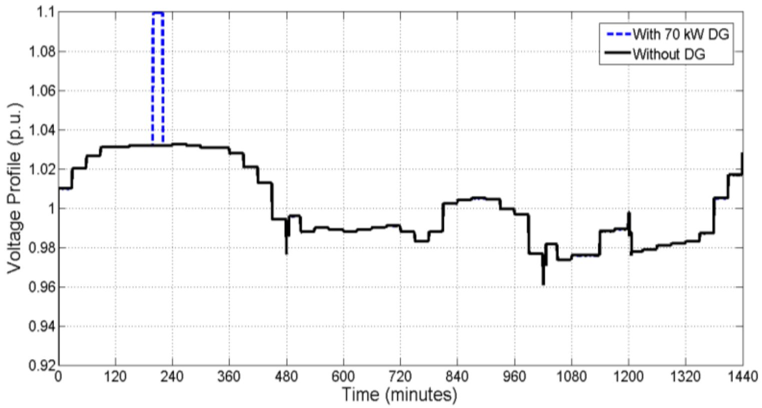
Smart Charging to Meet User Requirements

Charging period	Miles remaining	Target miles	SOH (cycled number)
3.0–4.0 am	0	59.2	1
3.0–5.0 am	0	59.2	1
3.0–5.30 am	0	59.2	1
3.0–6.0 am	0	59.2	1

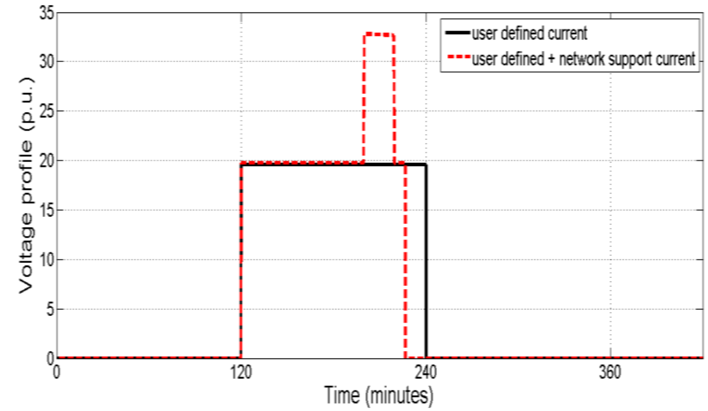




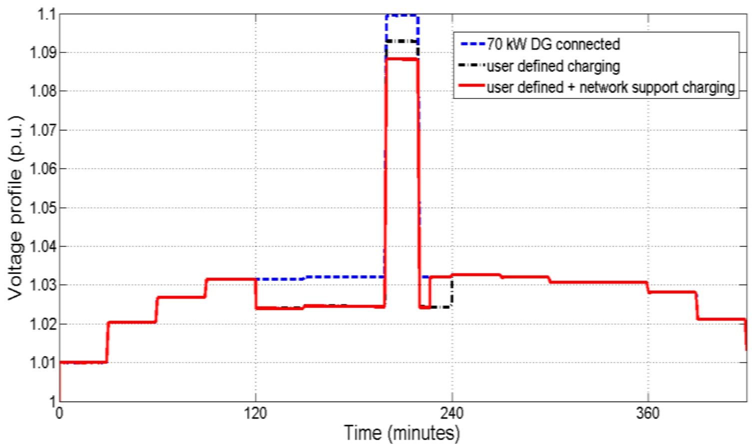
Smart Charging to Support Network Voltage



Daily voltage profiles at busbar 17 with and without 70 kW DG



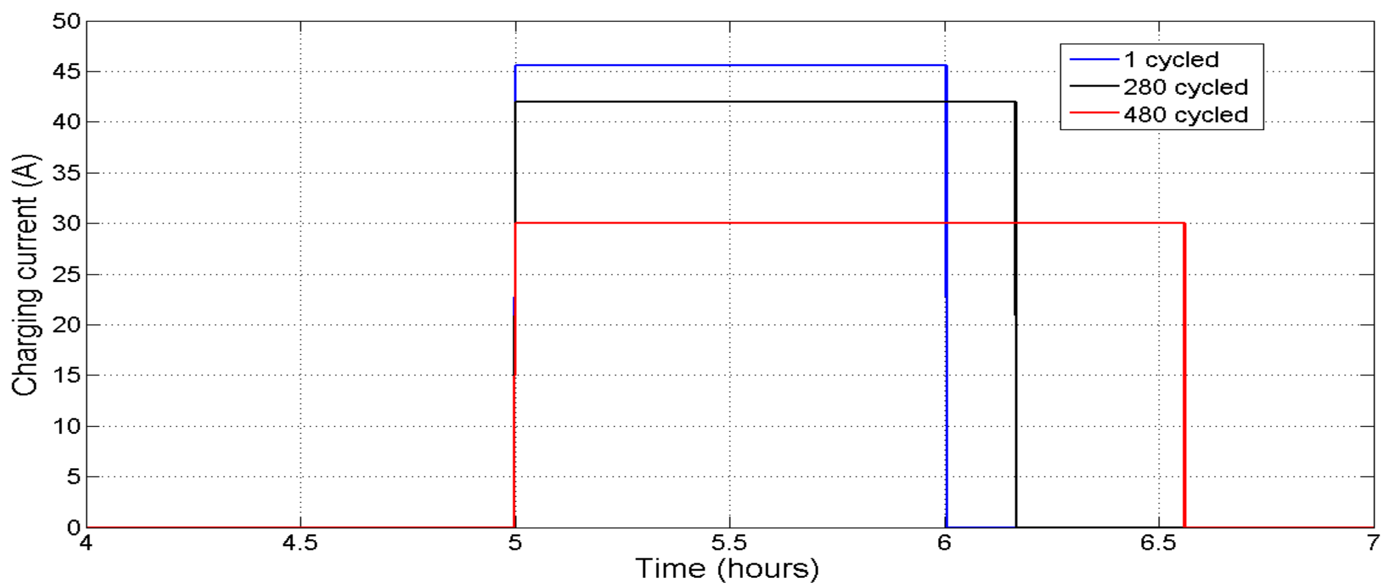
Charging current variation based on grid voltage support



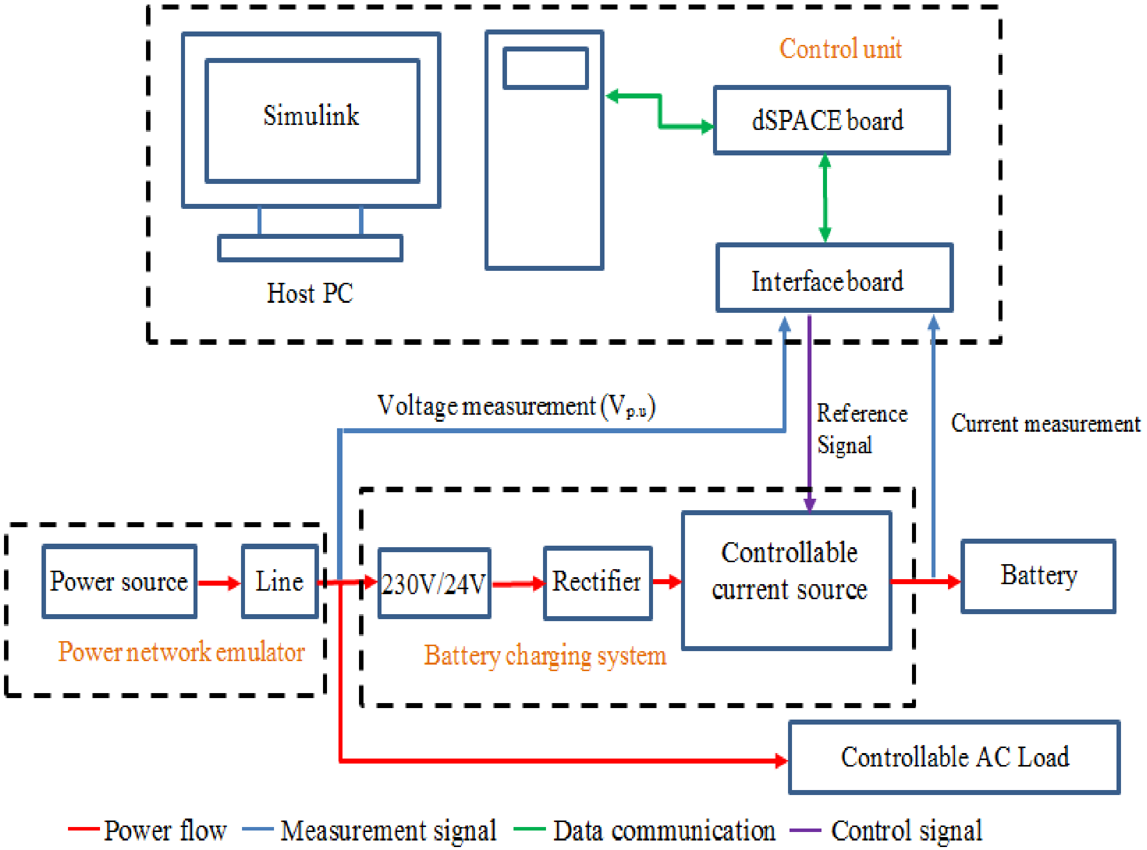
Daily voltage profiles at busbar 17 for different charging patterns

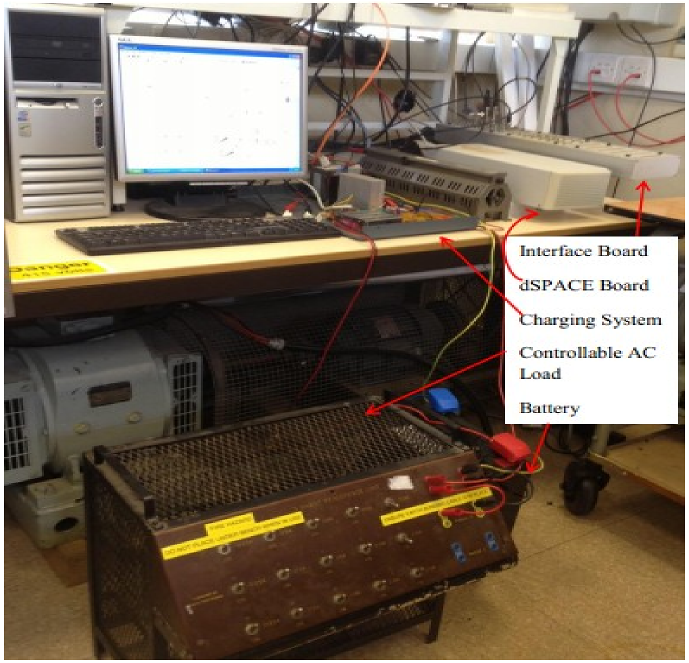
Smart Charging to Reduce Battery Aging

Charging period	Miles remaining	Target miles	SOH (cycled number)
5.0–6.0 am	8	69	1
5.0–6.0 am	8	69	280
5.0–6.0 am	8	69	480

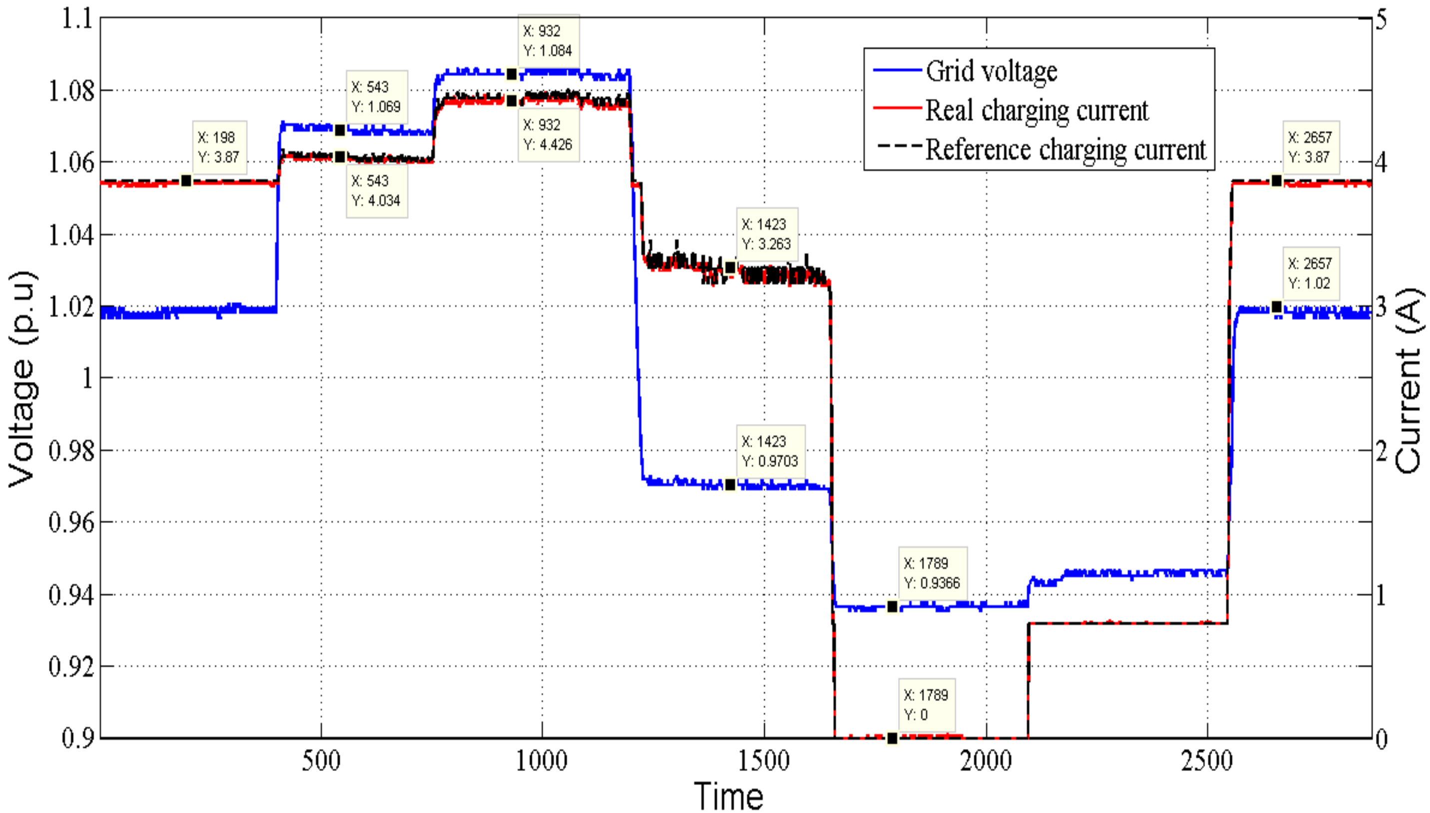


Experimental Work





Experimental Results



Summary

- EVs have high energy capacity and their mass deployment can have significant impacts (negative and positive) on the grid.
- Impacts of EVs on the grid and battery degradation need to be clearly defined in order to develop rules for smart charging.
- With appropriate smart controllers, EVs can provide ancillary services such as supply/demand matching and voltage/frequency control.
- Smart charging is needed in order to meet future demand of EV charging and potential opportunities to use the EV to support the grid.
- A smart EV charger can meet user requirements, support active network control and reduce battery degradation. Additional control signals may be used to enable maximizing charging from renewable energy and adjust for weather conditions, driving behaviour, etc.
- Smart charging will be implemented as part of the smart grid through smart meters, local controllers and two-way communication links.