



# Turku Raitiotie plan – Superbus charging system simulations

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# Overview

- Charging system requirements for battery electric double-articulated buses (Superbuses) in Turku studied
  - By energy flow simulations
- Longest and shortest planned routes were chosen for analysis
  - Longest route:  
Varissuo – Raisio
  - Shortest route:  
Varissuo – Matkakeskus



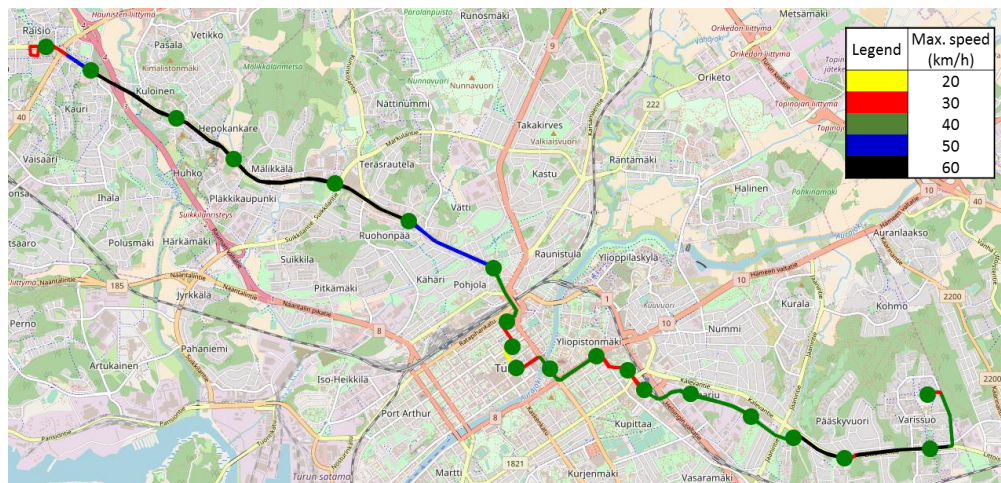
Photo: HESS SwissHybrid (© Jan Oosterhuis)

# Varissuo – Raisio route

- Length of route: 14.7 km
- Number of stops: 20 (green dots)
- Driving time in one direction: ~35 min
- Charging points at both end stops
- Turnaround times:
  - Raisio: 6 min
  - Varissuo: 14 min
- BRT concept
  - Buses not affected by traffic and have priority at traffic lights

- Constant stop times for each stop:

Stop name	Stop time (s)
Varissuo Pelttarinkatu	15
Varissuon liikekeskus	15
Hurttiviuri	15
Laukkavuori	15
Itäharju Tierankatu	15
Itäharju Karjakatu	15
Kupittaa kampus	25
Sairaala	20
Yliopisto	20
Tuomiokirkko	20
Kauppatori	25
Puutori	20
Matkakeskus	25
Raunistulan koulu	15
Ruohonpää	20
Länsikeskus	15
Raisio Mälikkälä	15
Raisio Kuloinen	15
Raisio kaupungintalo	15
Raisio keskusta	15



- <20 passengers: 15s
- 20-40 passengers: 20s
- >40 passengers: 25s

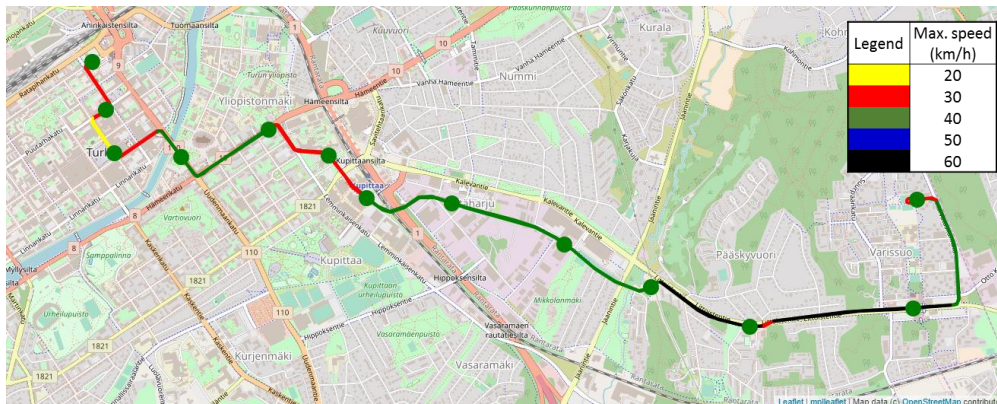
# Varissuo – Matkakeskus route

- Length of route: 7.8 km
- Number of stops: 13 (green dots)
- Driving time in one direction: ~22 min
- Charging points at both end stops
- Turnaround times:
  - Raisio: 6 min
  - Varissuo: 10 min
- BRT concept
  - Buses not affected by traffic and have priority at traffic lights

- Constant stop times for each stop:

Stop name	Stop time (s)
Varissuo Pelttarinkatu	15
Varissuon liikekeskus	15
Hurtтивуori	15
Laukkavuori	15
Itäharju Tierankatu	15
Itäharju Karjakatu	15
Kupittaa kampus	25
Sairaala	20
Yliopisto	20
Tuomiokirkko	20
Kauppatori	25
Puutori	20
Matkakeskus	25

- <20 passengers: 15s
- 20-40 passengers: 20s
- >40 passengers: 25s

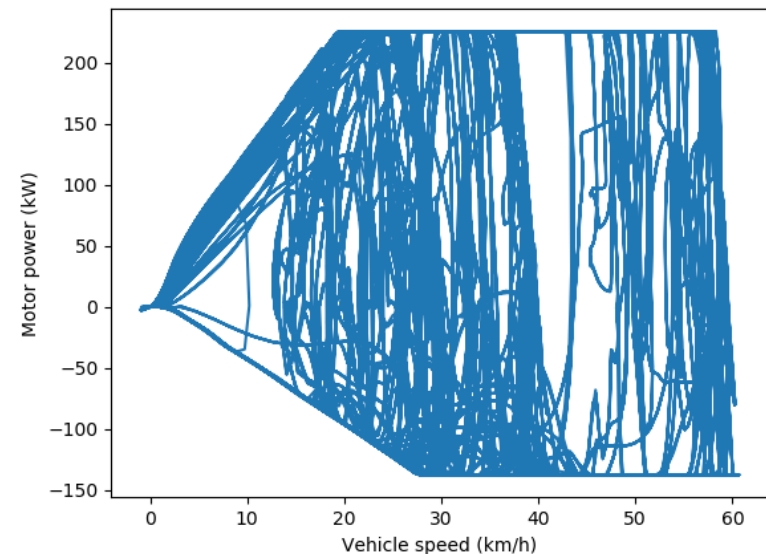


# Simulation tool

- Simulations conducted in VTT's in-house map-based energy flow simulation tool "GIS tool"
- GIS tool presented in
  - M. Ranta et al. "*Method including Power Grid Model and Route Simulation to Aid Planning and operation of an Electric Bus Fleet*" 2016.
- GIS tool is comprised of two modules
  - Route design module
    - Used to create routes based on digital maps
    - Route characteristics (such as speed limits and elevations) fetched from open sources
  - Vehicle simulation module
    - Turns routes into speed profiles
    - Performs energy flow simulations

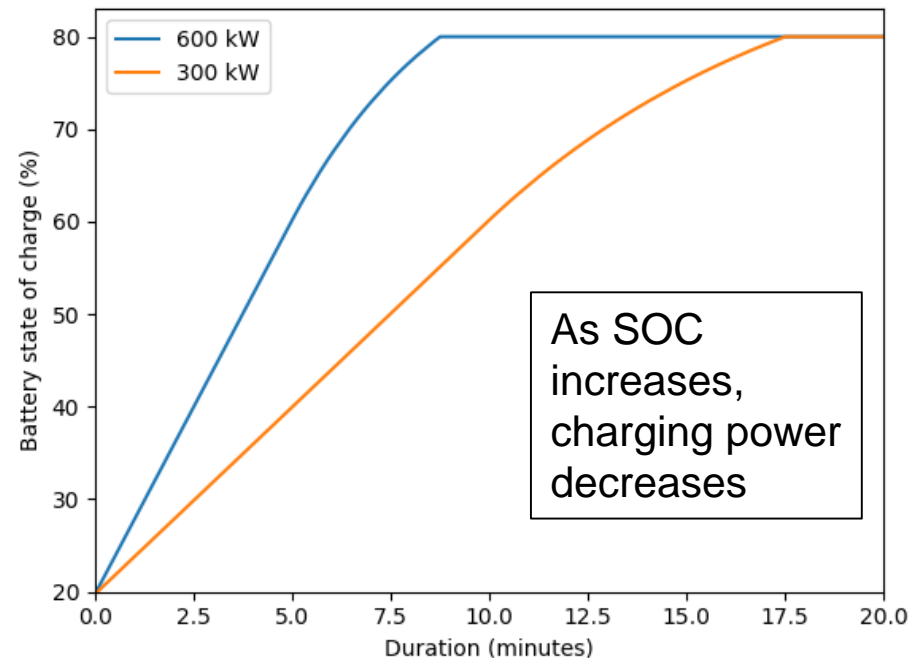
## Bus model

- Validated battery electric bus model tweaked to represent double-articulated battery electric bus
- Length: 24m
- Gross weight (with passengers): 35 tons
- Battery capacity: 120 kWh
- Motor nominal power: 230 kW
- Motor nominal speed: 1600 rpm
- Nominal propulsive power at 19 km/h
- Nominal regeneration power at 28 km/h



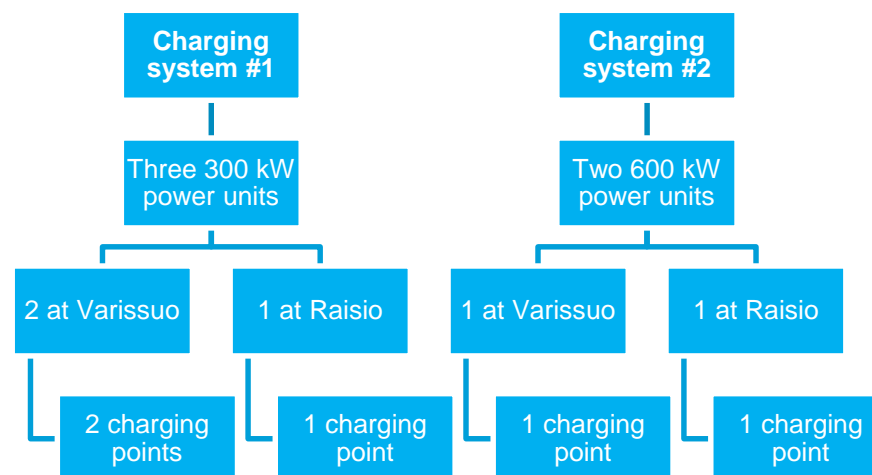
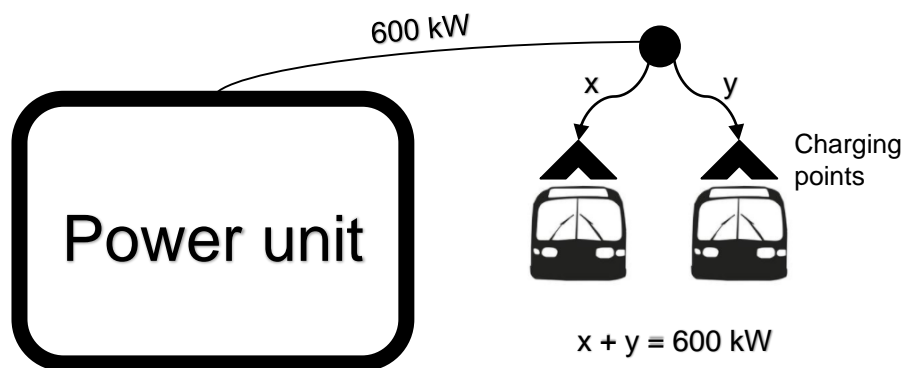
# Charging system assumptions

- Full-charge: 80% battery state of charge (SOC)
  - 100% SOC typically not achieved with high power charging
- Charging power decreases when SOC increases
- Total connection time: 31 seconds
  - Includes attachment, handshake and detachment
  - Based on observations in the electric bus system of Helsinki
- Charging system assumptions based on current state of technology
  - Improvements expected in the future



# Simulated charging systems

- Simulations conducted with two different charging systems
  - Charging system #1
  - Charging system #2
- **In the simulations, each power unit has one charging point**
  - While in reality, one power unit can have multiple charging points:





# Simulation cases for Varissuo – Raisio

Case	Charging system	Charging points	Headway
CASE 1	1	3 x 300 kW	7.5min
CASE 2	1	3 x 300 kW	5min
CASE 3	1	2* x 300 kW	7.5min
CASE 4	1	2** x 300 kW	7.5min
CASE 5	2	2 x 600 kW	7.5min
CASE 6	2	2 x 600 kW	5min
CASE 7	2	1* x 600 kW	5min & 7.5min
CASE 8	2	1** x 600 kW	5min & 7.5min

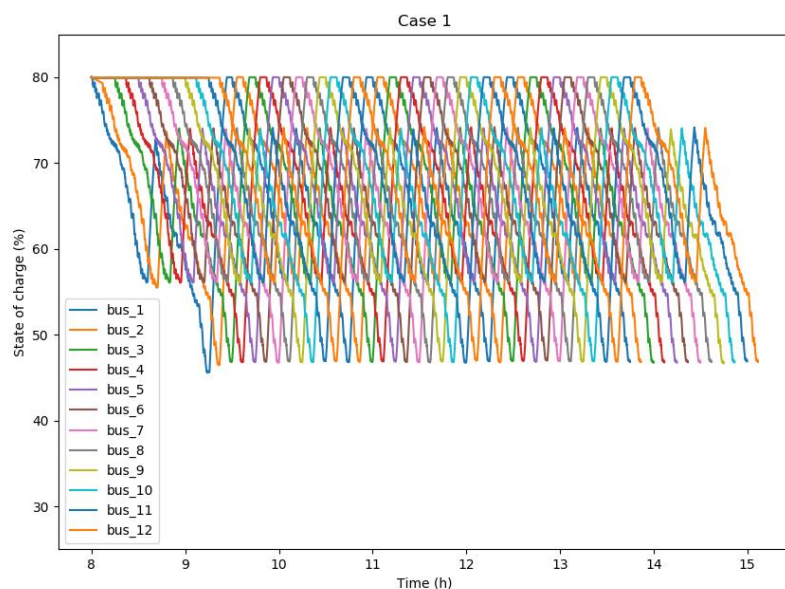
\*Power unit malfunction at Raisio

\*\*Power unit malfunction at Varissuo

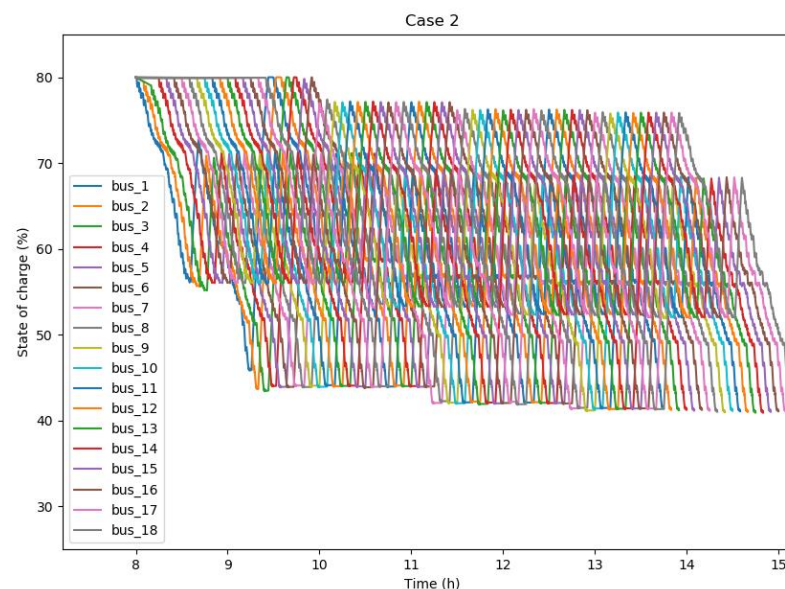
- 8 simulation cases
  - 7.5min and 5min headways
- Sensitivity to power unit malfunctions analyzed
  - Power unit malfunction at Raisio
  - Power unit malfunction at Varissuo

# Simulation cases for Varissuo – Raisio

- Cases with 7.5min headway were simulated with a fleet of 12 buses



- Cases with 5min headway were simulated with a fleet of 18 buses

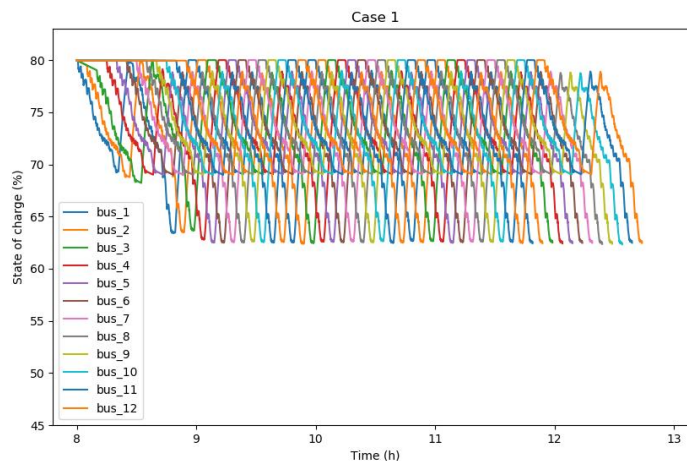


# Simulation cases for Varissuo – Matkakeskus

- 6 simulation cases
  - 5min headway
- Sensitivity to power unit malfunctions analyzed
  - Power unit malfunction at Matkakeskus
  - Power unit malfunction at Varissuo
- Simulated with fleet of 12 buses:

Case	Charging system	Charging points	Headway
CASE 1	1	3 x 300 kW	5min
CASE 2	1	2* x 300 kW	5min
CASE 3	1	2** x 300 kW	5min
CASE 4	2	2 x 600 kW	5min
CASE 5	2	1* x 600 kW	5min
CASE 6	2	1** x 600 kW	5min

\*Power unit malfunction at Raisio  
 \*\*Power unit malfunction at Varissuo

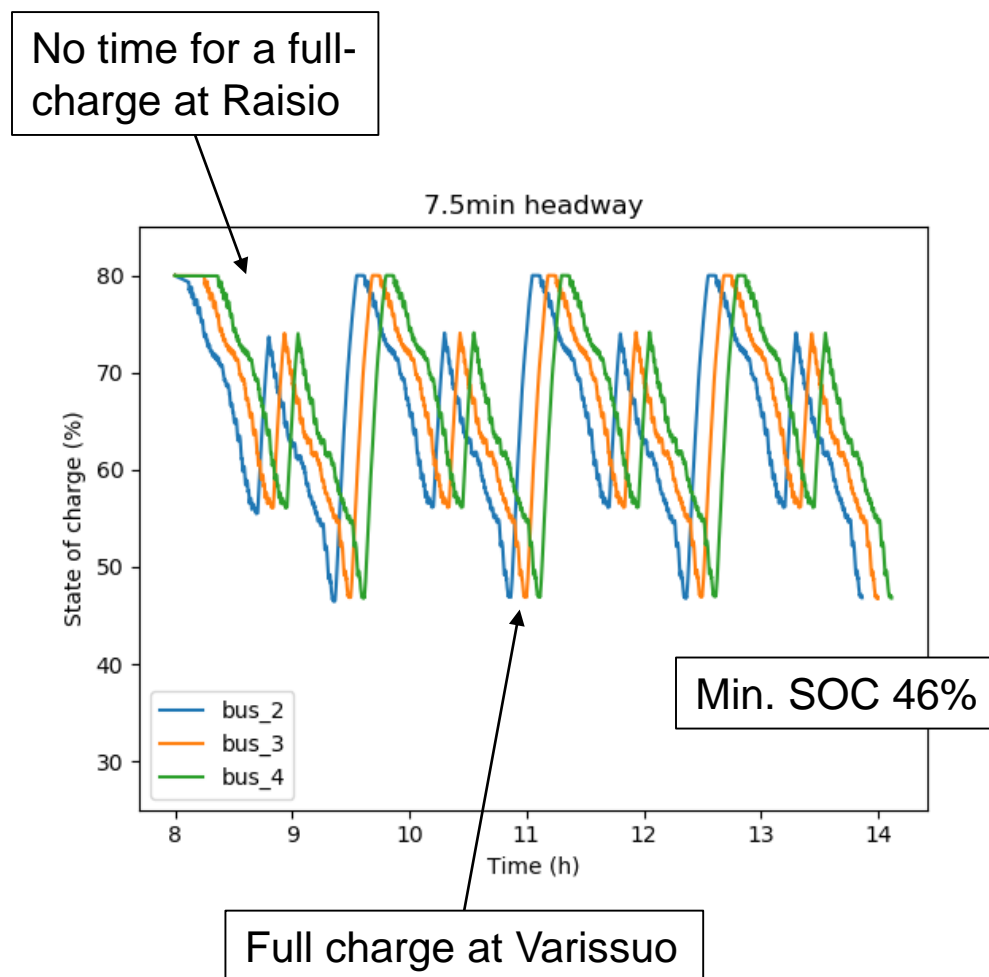




# Varissuo – Raisio simulations

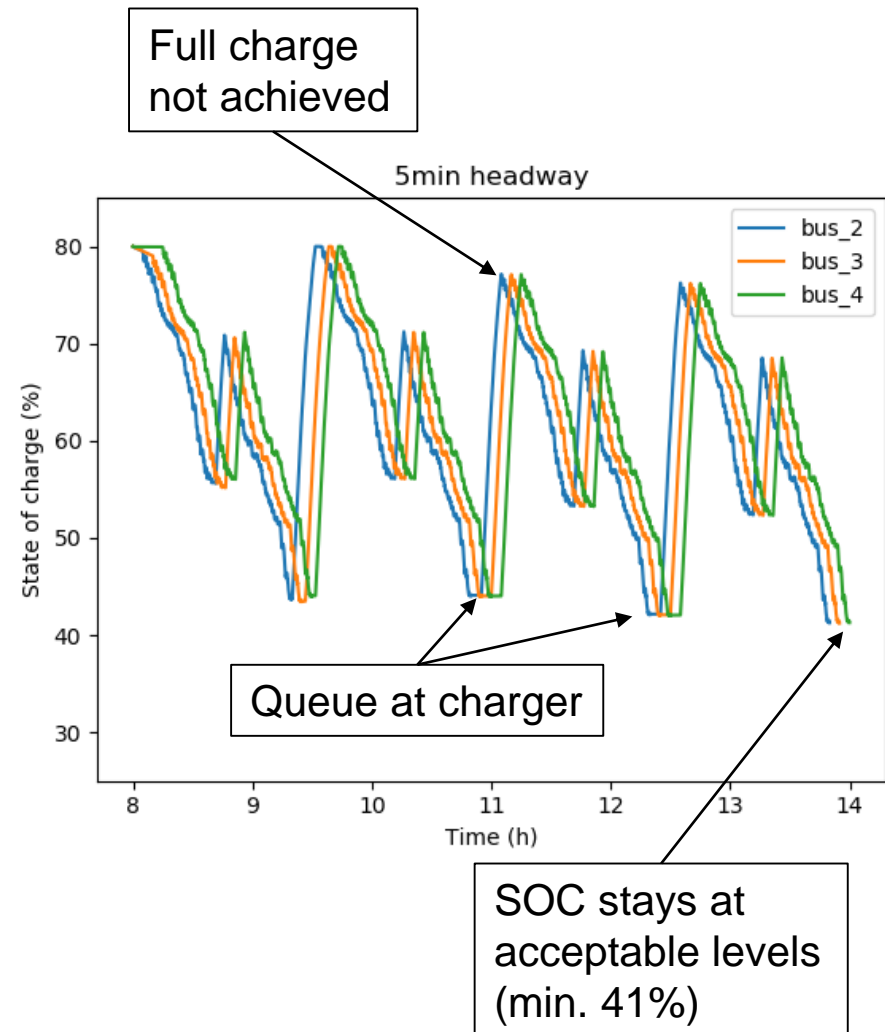
# CASE 1 – Charging system #1 – 7.5 min headway

- 3 x 300 kW charging points:
  - 2 at Varissuo
  - 1 at Raisio
- Enough time for a full-charge (SOC 80%) at Varissuo
  - ~4min time clearance after charging at Varissuo
- Not enough time for a full-charge at Raisio
- Extended operation is possible
  - Quite limited margin for delays



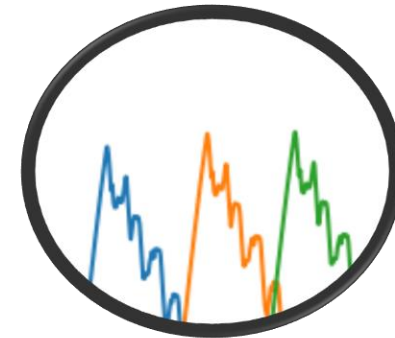
## CASE 2 – Charging system #1 – 5 min headway

- 3 x 300 kW charging points:
  - 2 at Varissuo
  - 1 at Raisio
- Full charge not achieved
- SOC stays at acceptable levels
  - Keeps decreasing a little during the day
- Extended operation may be possible:
  - Very limited margin for delays
  - Normal operation possible for rush hour



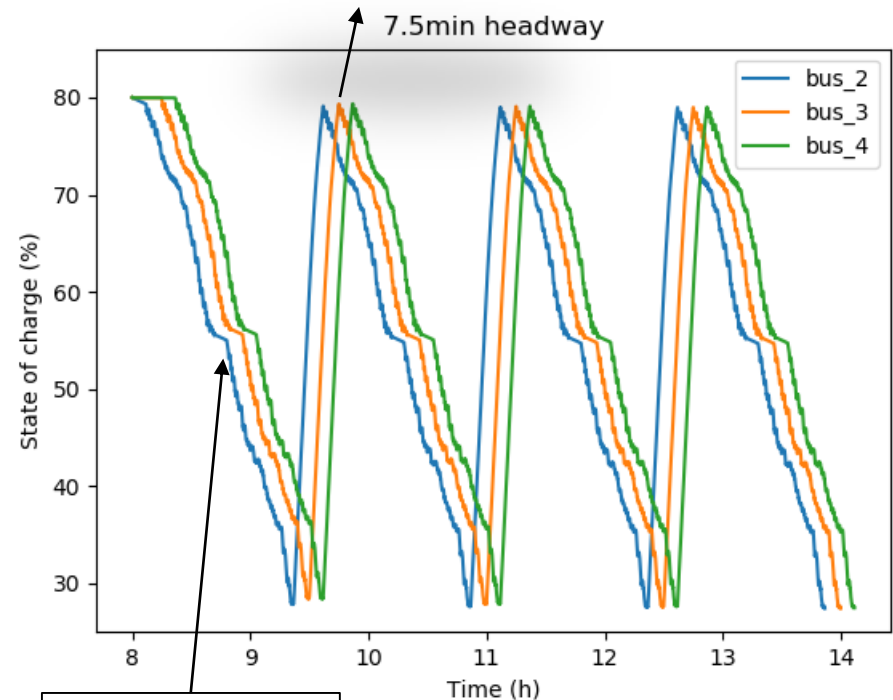
# CASE 3 – Charging system #1 – "Power unit malfunction at Raisio"

- 2 x 300kW charging points:
  - 2 at Varissuo
  - 0 at Raisio (power unit malfunction)
- Extended operation might be possible with 7.5min headway
  - No margin for delays
  - SOC decreases to low levels (<30%)
    - Engine power may be cut at low capacity
    - Reduces battery life
- Charging takes ~15min (27% → 80%)
  - **Not enough charging capacity for 5min headway**



Full-charge barely achieved

Sensitive to delays

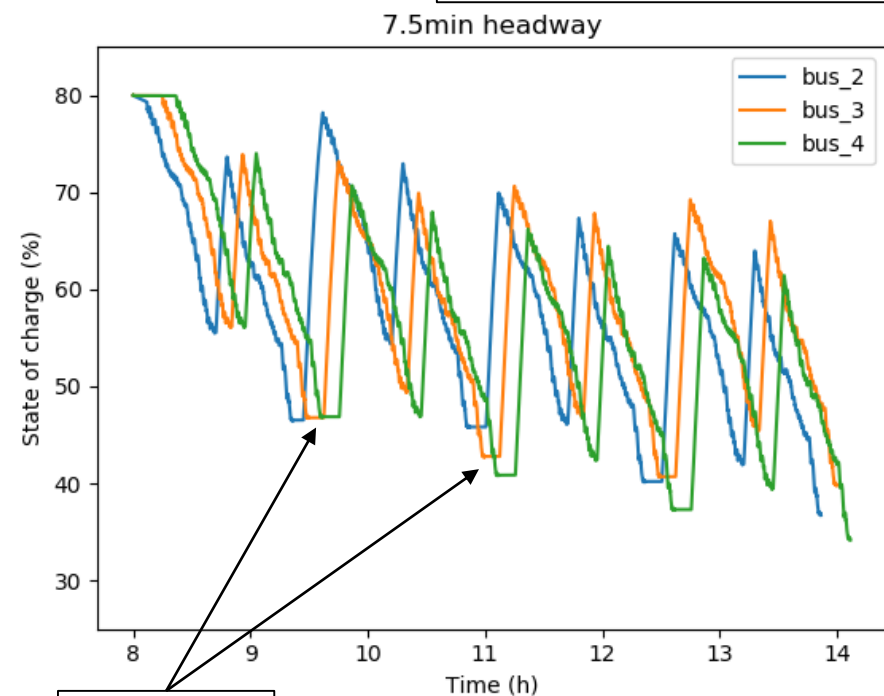


No charging at Raisio

# CASE 4 – Charging system #1 – ”Power unit malfunction at Varissuo”

- 2 x 300 kW charging points:
  - 1 at Varissuo (power unit malfunction)
  - 1 at Raisio
- Charging takes about **10 min** (SOC: 48 % → 80%)
  - Causes queue at Varissuo charger
- Normal operation plausible for short period only (e.g. rush hour)
  - Only with 7.5min headway

Not enough time for a full-charge at Raisio or Varissuo



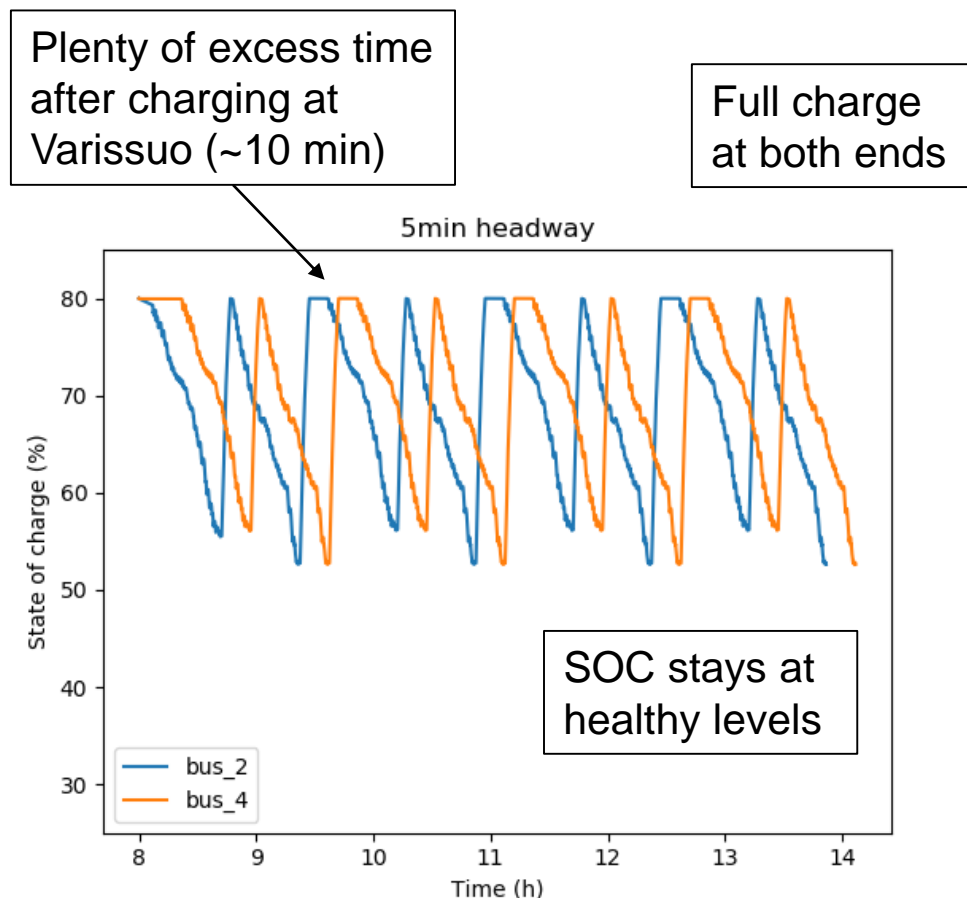
Queue at Varissuo charger

SOC keeps decreasing during the day



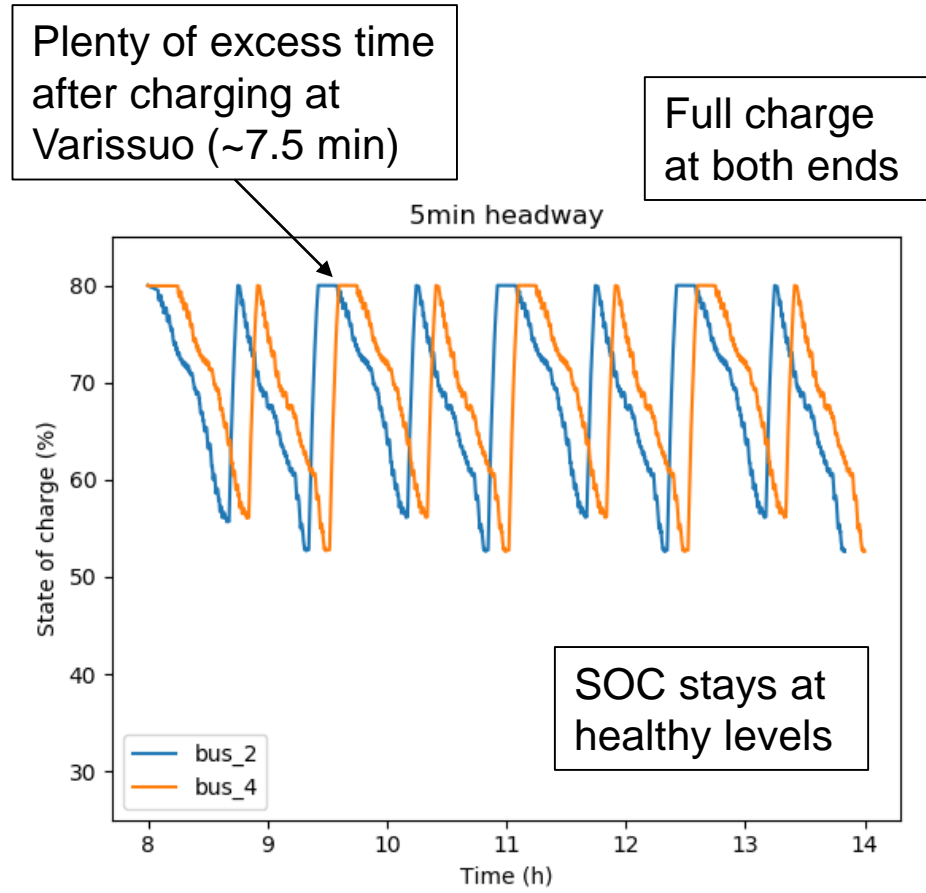
## CASE 5 – Charging system #2 – 7.5 min headway

- 2 x 600 kW charging points:
  - 1 at Varissuo
  - 1 at Raisio
- Plentiful time after charging
  - ~10min of excess time at Varissuo
  - ~3min of excess time at Raisio
- Extended operation plausible
  - Excellent margin for delays



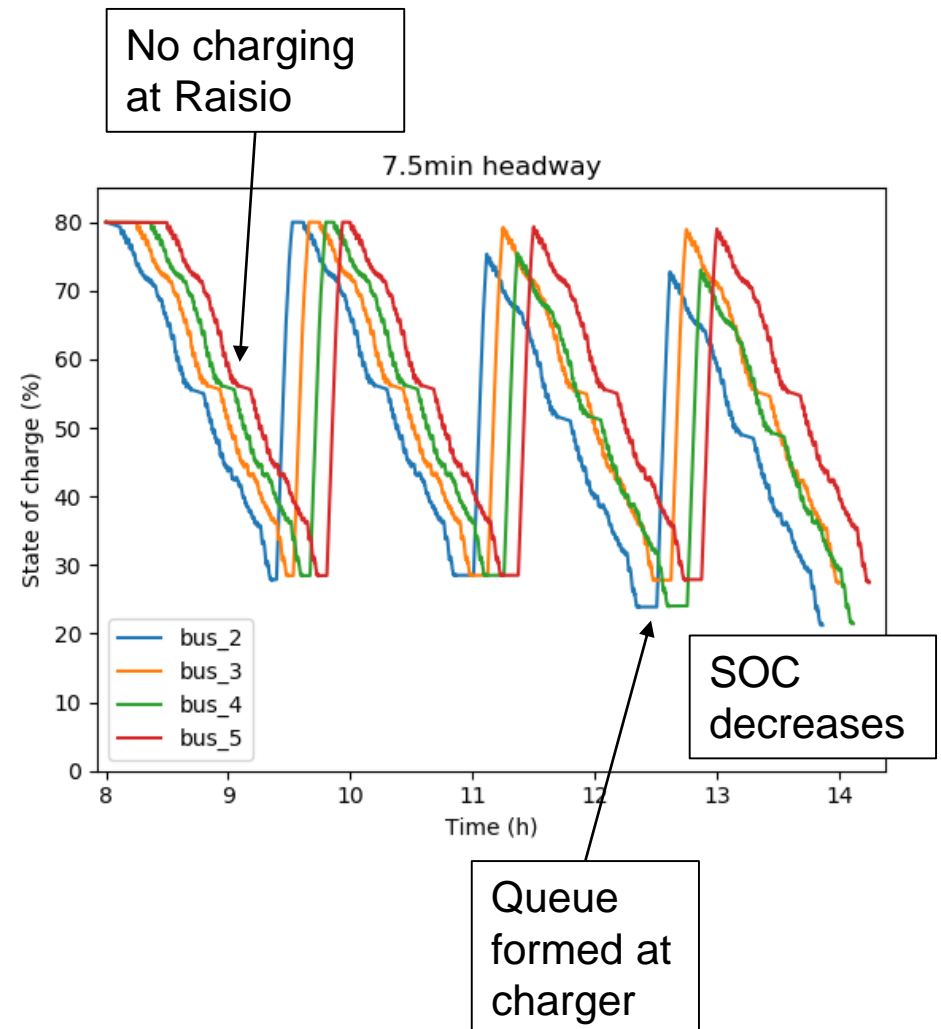
# CASE 6 – Charging system #2 – 5 min headway

- 2 x 600 kW charging points:
  - 1 at Varissuo
  - 1 at Raisio
- Plentiful time after charging
  - ~7.5min of excess time at Varissuo
  - ~0.5min of excess time at Raisio
- Extended operation plausible
  - Good margin for delays



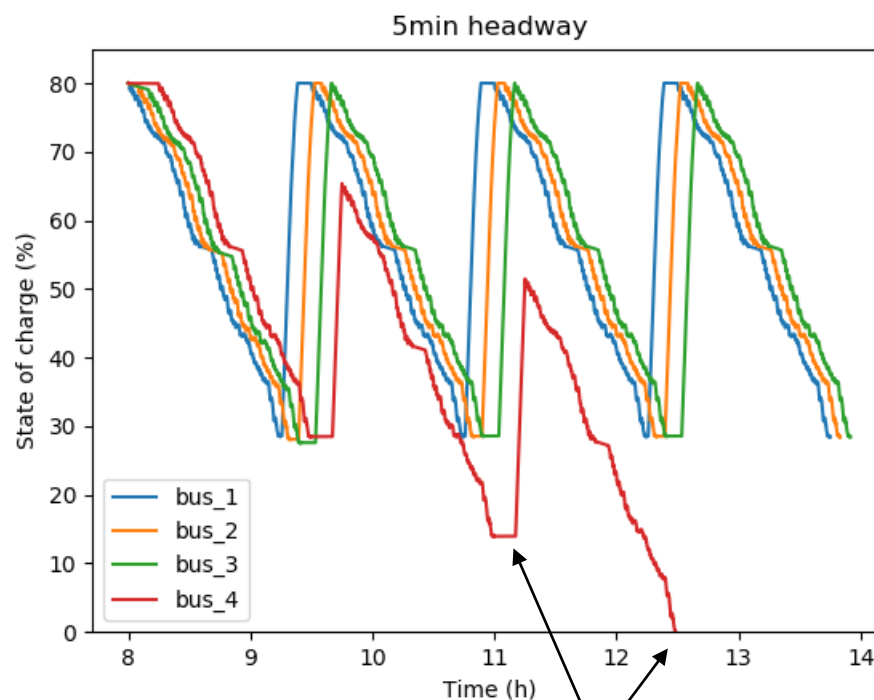
## CASE 7.1 – Charging system #2 – "Power unit malfunction at Raisio" – 7.5min headway

- 1 x 600kW charging point:
  - 1 at Varissuo
  - 0 at Raisio (power unit malfunction)
- Some queue formed at the charger, however:
  - Normal operation plausible for short period only (e.g. rush hour)
    - At least 4 back-and-forth trips



## CASE 7.2 – Charging system #2 – ”Power unit malfunction at Raisio” – 5min headway

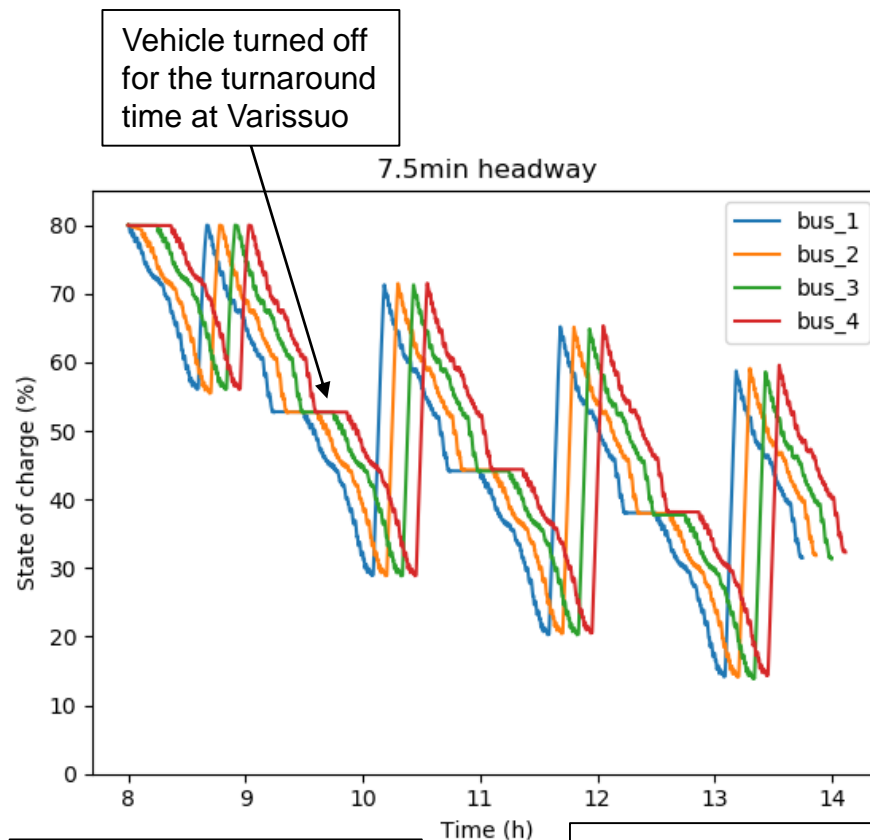
- 1 x 600kW charging point:
  - 1 at Varissuo
  - 0 at Raisio (power unit malfunction)
- Only first three buses have enough time to charge
- Normal operation plausible for very short period only
  - No more than 2 back-and-forth trips
- Operation time can be extended:
  - Ex 1: Charging the buses to 70% SOC instead of full-charge
  - Ex 2: Setting up two charging points and prioritising vehicles with low SOC



Increased queue time  
leads to depleted battery

## CASE 8.1 – Charging system #2 – "Power unit malfunction at Varissuo" – 7.5min headway

- 1x 600kW charging point:
  - 0 at Varissuo (power unit malfunction)
  - 1 at Raisio
- Maximum time for charging at Raisio is ~5.5min
  - No queue as charging time is shorter than headway
- Normal operation plausible for short period only (e.g. rush hour)
  - At least 3 back-and-forth trips
  - Extremely vulnerable for delays caused by traffic, increased stopping time at bus stops etc.

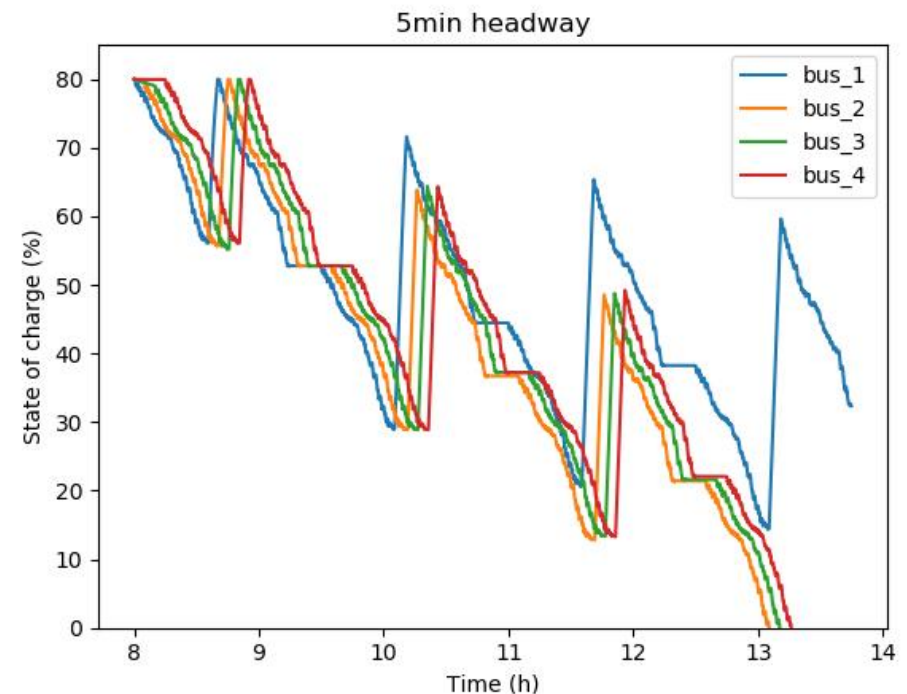


Maximum time for charging ~5.5min at Raisio

SOC keeps decreasing during the day

## CASE 8.2 – Charging system #2 – "Power unit malfunction at Varissuo" – 5min headway

- 1x 600kW charging point:
  - 0 at Varissuo (power unit malfunction)
  - 1 at Raisio
- Only first the bus has enough time to charge
  - Others have to wait 1-1.5 min
    - Extra waiting time leads to depleted battery
- Normal operation plausible for short period only (e.g. rush hour)
  - At least 2 back-and-forth trips
  - Extremely vulnerable for delays caused by traffic, increased stopping time at bus stops etc.

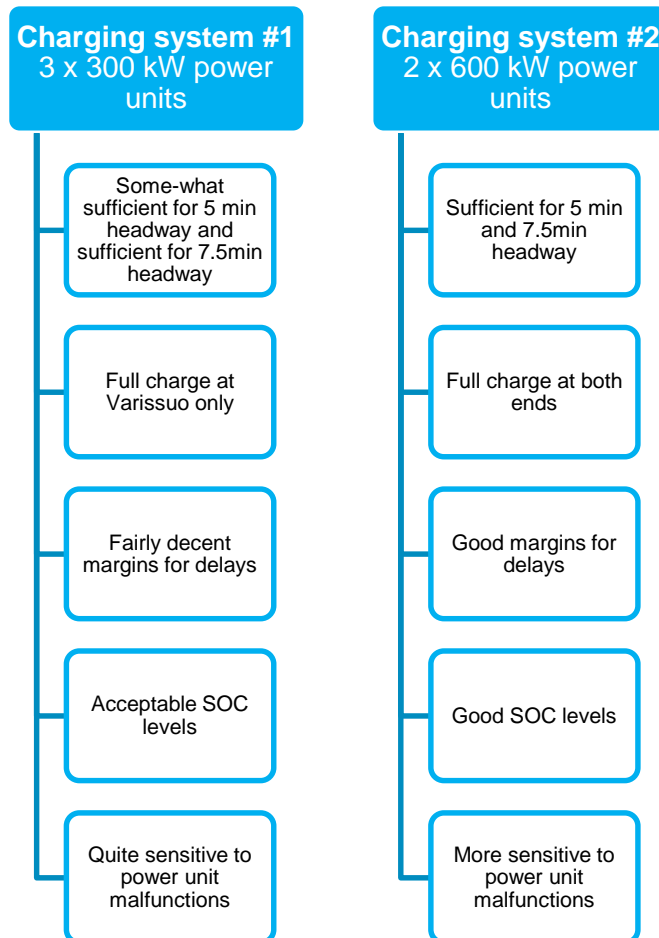


# Simulation case results

Case	Charging system	Charging points	Headway	Time after full-charge Varissuo	Time after full-charge Raisio	Min. SOC	Buffer for delays	Normal operation
CASE 1	1	3 x 300 kW	7.5min	~4min	Full charge not achieved	46%	Limited	Extended
CASE 2	1	3 x 300 kW	5min	Full charge not achieved	Full charge not achieved	41%	Very limited	Extended may be plausible
CASE 3	1	2* x 300 kW	7.5min	None	No charging	27%	None	Extended may be plausible
CASE 4	1	2** x 300 kW	7.5min	Full charge not achieved	Full charge not achieved	36%	None	For short period
CASE 5	2	2 x 600 kW	7.5min	~10min	~3min	53%	Excellent	Extended
CASE 6	2	2 x 600 kW	5min	~7.5min	~0.5min	53%	Good	Extended
CASE 7	2	1* x 600 kW	5min 7.5min	Full charge not achieved	No charging	5min: 0% 7.5min: 20%	5min: None 7.5 min: None	For short period
CASE 8	2	1** x 600 kW	5min 7.5min	No charging	Full charge not achieved	5min: 0% 7.5min: 14%	5min: None 7.5 min: None	For short period

\*Power unit malfunction at Raisio  
 \*\*Power unit malfunction at Varissuo

# Conclusions for Varissuo-Raisio



- Temporary operation possible when the buses are charged only in one end station
  - E.g. in case of a power unit malfunction
- Charging system #2 with at least one extra 300 kW (or higher) power unit recommended
  - Extra power units increase reliability of the bus system
- 600kW power units recommended to have at least two charging points
  - Dynamic charging power allocation
  - Saves time in case of queue

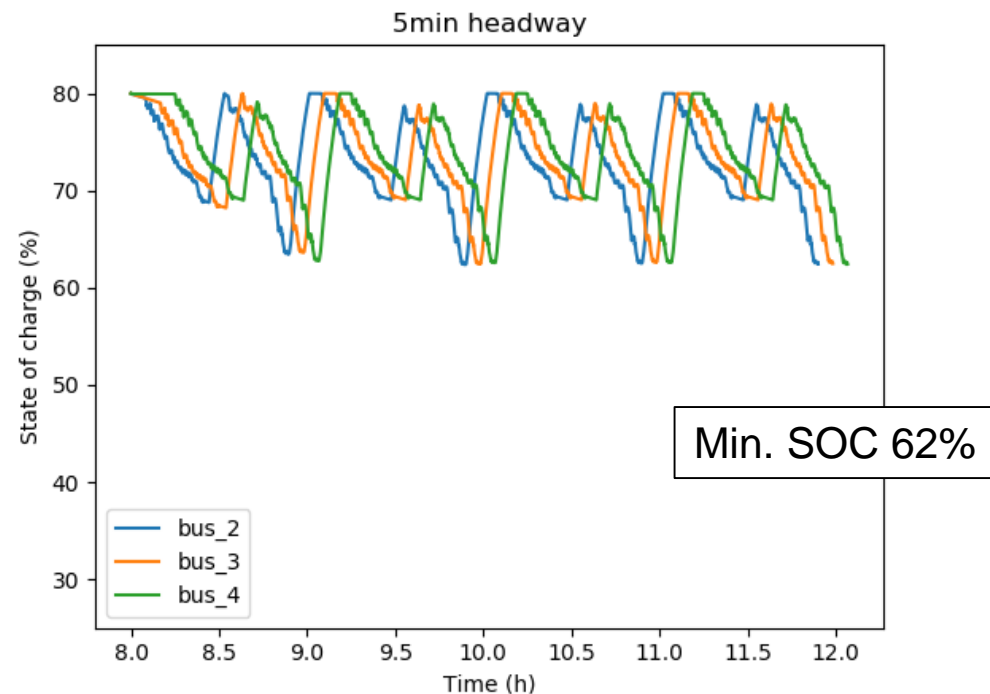




# Varissuo – Matkakeskus simulations

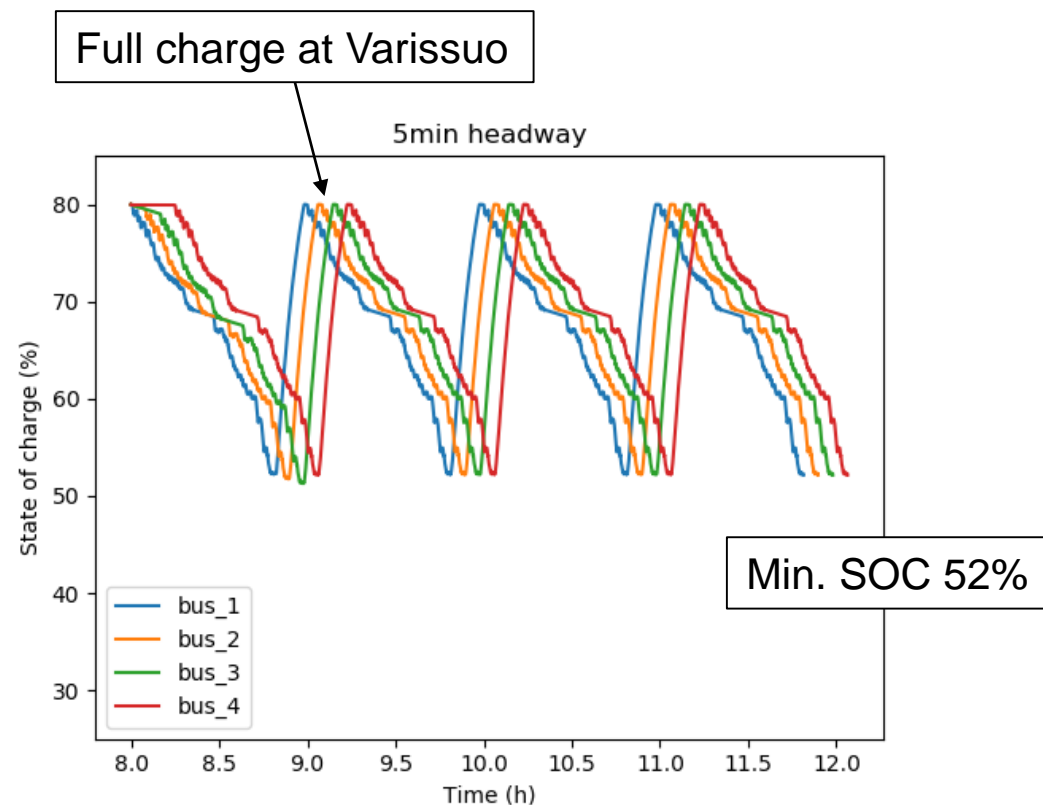
# CASE 1 – Charging system #1 – 5 min headway

- 3 x 300 kW charging points:
  - 2 at Varissuo
  - 1 at Matkakeskus
- Enough time for a full-charge (SOC 80%) at Varissuo
  - ~4min time clearance after charging at Varissuo
- High SOC levels
- Extended operation plausible
  - Some margin for delays



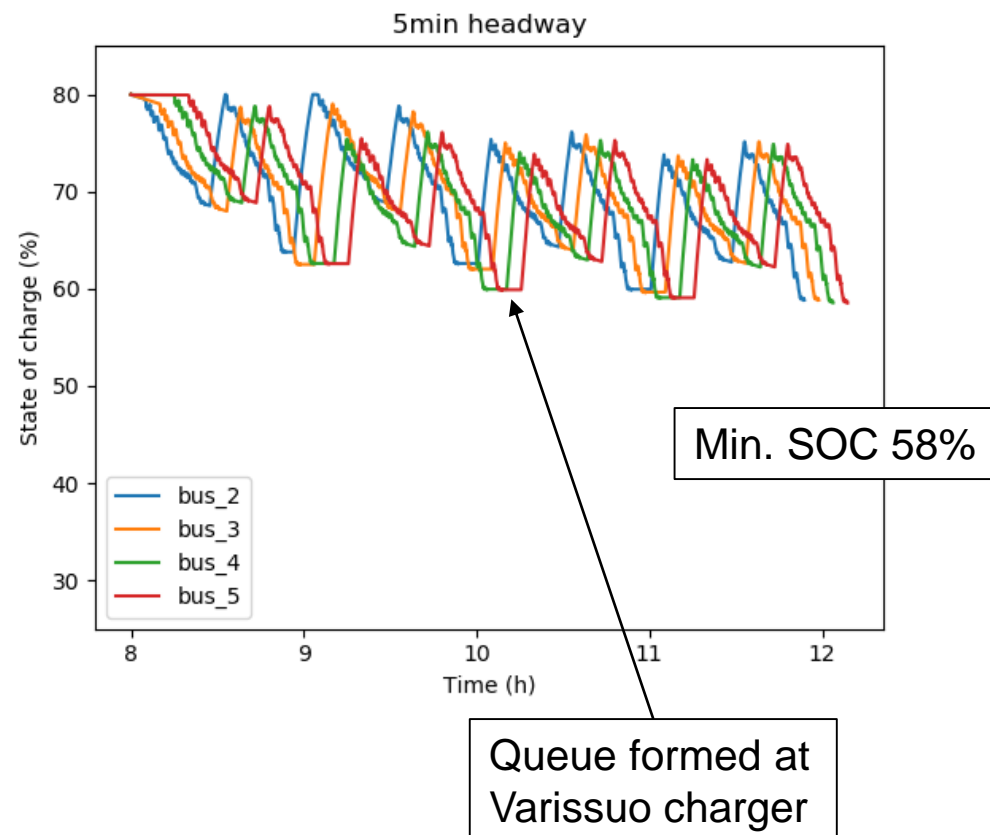
## CASE 2 – Charging system #1 – Power unit malfunction at Matkakeskus”

- 2 x 300 kW charging points:
  - 2 at Varissuo
  - 0 at Matkakeskus (power unit malfunction)
- Enough time for a full-charge (SOC 80%) at Varissuo
  - ~1.5min time clearance after charging
- Good SOC levels
- Extended operation possible
  - Less margin for delays



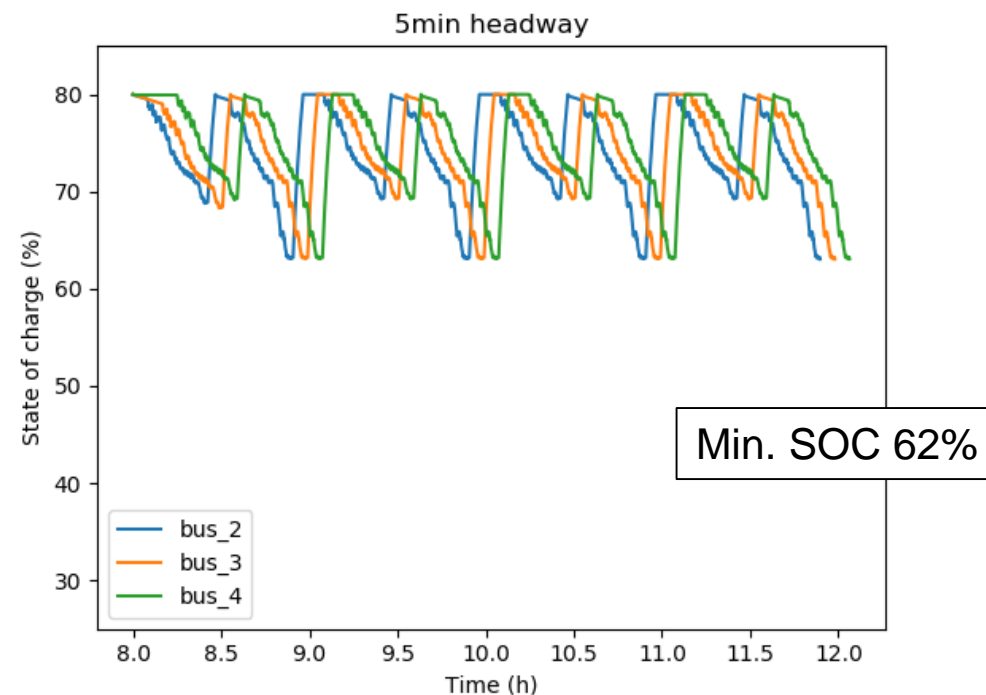
## CASE 3 – Charging system #1 – Power unit malfunction at Varissuo”

- 2 x 300 kW charging points:
  - 1 at Varissuo (power unit malfunction)
  - 1 at Matkakeskus
- Full-charge not achieved at either end
- Queue at Varissuo charger
- Extended operation possible as SOC stays high
  - Limited margin for delays



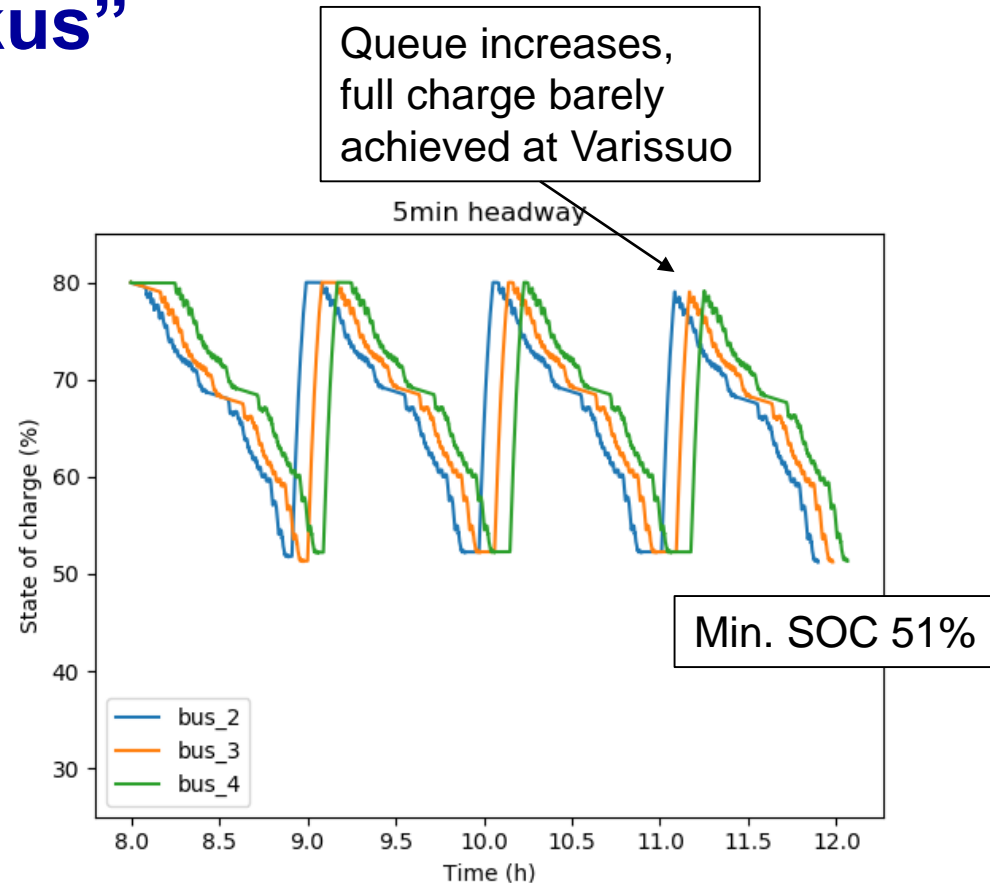
## CASE 4 – Charging system #2 – 5 min headway

- 2 x 600 kW charging points:
  - 1 at Varissuo
  - 1 at Matkakeskus
- Enough time for a full-charge (SOC 80%) at both ends
  - ~7min time clearance after charging at Varissuo
  - ~5min time after charging at Matkakeskus
- High SOC levels
- Extended operation plausible
  - Good margin for delays



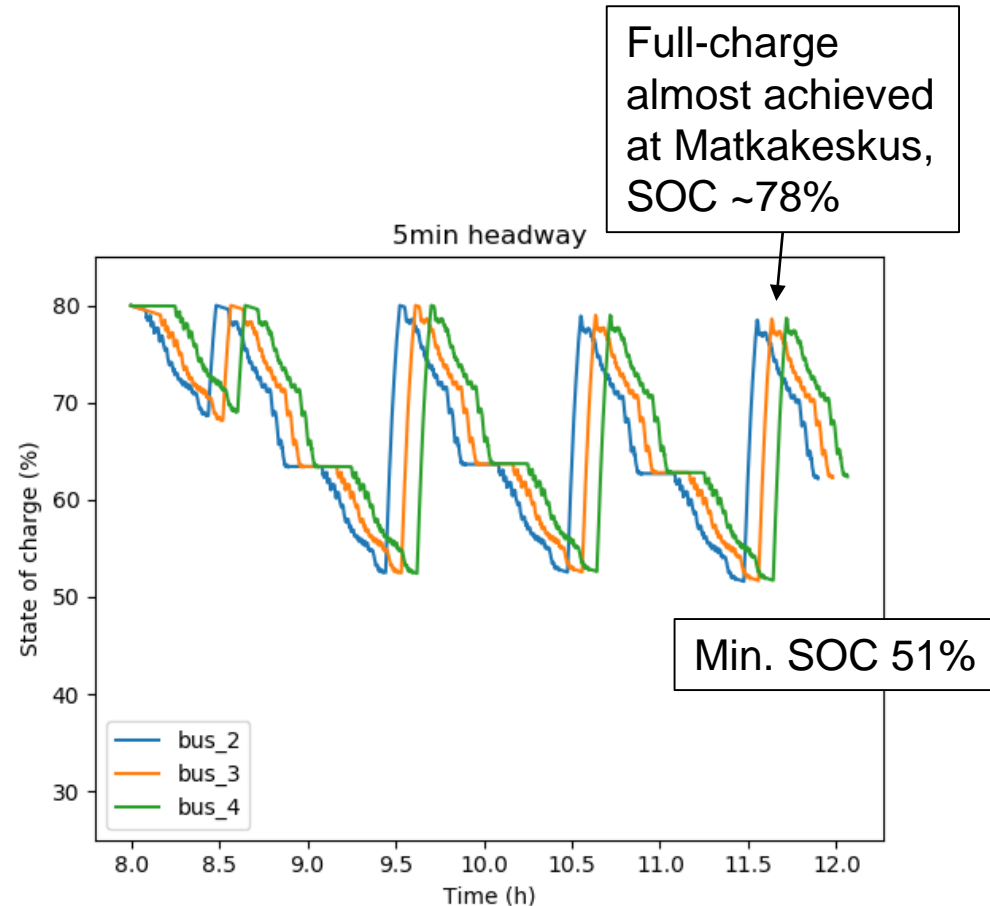
## CASE 5 – Charging system #2 – Power unit malfunction at Matkakeskus”

- 1 x 600 kW charging points:
  - 1 at Varissuo
  - 0 at Matkakeskus (power unit malfunction)
- Enough time for a full-charge (SOC 80%) at Varissuo
  - Some queue formed at Varissuo charger
- Good SOC levels
- Extended operation possible
  - Limited margin for delays



## CASE 6 – Charging system #2 – Power unit malfunction at Varissuo”

- 1 x 600 kW charging points:
  - 0 at Varissuo (power unit malfunction)
  - 1 at Matkakeskus
- Full-charge almost achieved at Matkakeskus
- Good SOC levels
  - However, max. SOC decreases a little during the day
- Extended operation possible
  - Limited margin for delays



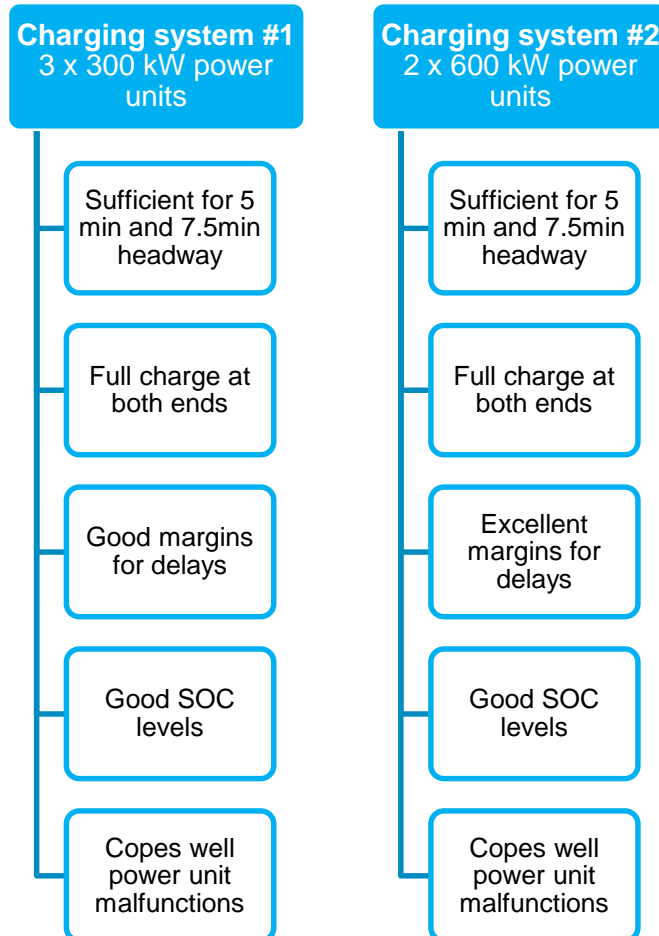
# Simulation case results

Case	Charging system	Charging points	Headway	Time after full-charge Varissuo	Time after full-charge Matkak.	Min. SOC	Buffer for delays	Normal operation
CASE 1	1	3 x 300 kW	5min	~4min	~0.5min	62%	Good	Extended
CASE 2	1	2* x 300 kW	5min	~1.5min	No charging	52%	Some	Extended
CASE 3	1	2** x 300 kW	5min	None	None	58%	Some	Extended may be plausible
CASE 4	2	2 x 600 kW	5min	~7min	~5min	62%	Excellent	Extended
CASE 5	2	1* x 600 kW	5min	Decreases	No charging	53%	Some	Extended
CASE 6	2	1** x 600 kW	5min	No charging	Decreases	51%	Some	Extended may be plausible

\*Power unit malfunction at Raisio  
 \*\*Power unit malfunction at Varissuo



# Conclusions for Varissuo – Matkakeskus



- Extended operation possible when the buses are charged only at one end station
  - E.g. in case of a power unit malfunction
- Both charging systems are plausible for 5min headway
  - 7.5min headway operation even more reliable
  - Extra power units increase reliability of the bus system
- 600kW power units recommended to have at least two charging points
  - Dynamic charging power allocation
  - Saves time in case of queue



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