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# Scenario Analyses of a Dynamic LVDC Smart-Trolleybus-Network with Battery-Assisted Traction Loads

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Research Group:
Smart Grids and Smart Systems

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**3rd E-Mobility Power System Integration Symposium**

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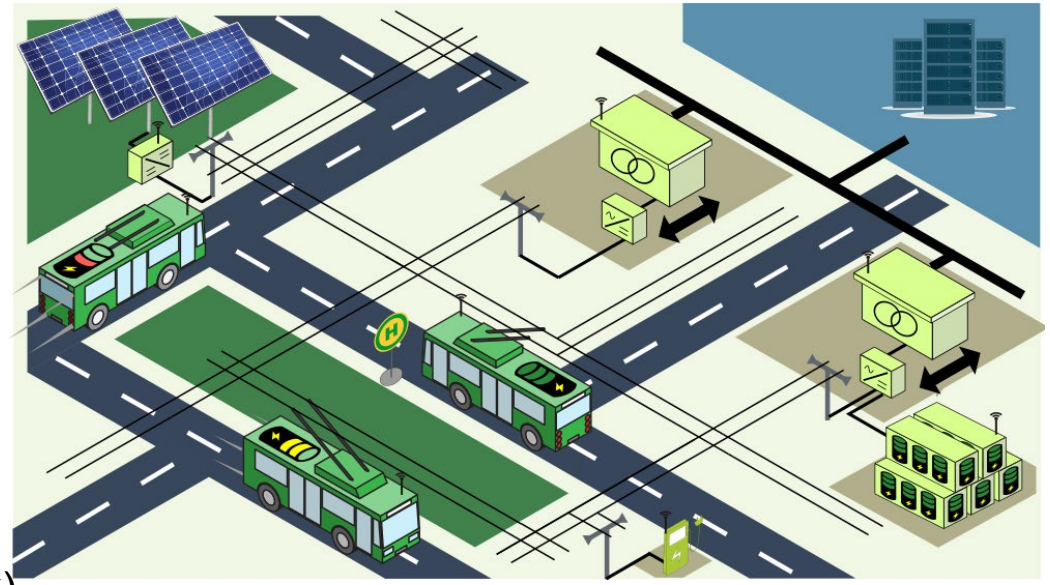
# Introduction

## Project "BOB[1] Solingen"

- New Components
  - Battery-Trolleybuses (BOBs)
  - Photovoltaic Systems (PV)
  - Electric Vehicle Charging Stations (EV)
  - Stat. Storage Systems
  - Bi-directional Substations
- Simulation Tool
  - Traffic Network Model
  - Electrical Network Model (Low Voltage Direct Current Traction Network)
  - Buses Model (Trolleybuses, BOBs)
  - Modelling: Photovoltaic Systems, Electric Vehicle Charging Stations and Stat. Storage Systems
  - Network state calculation (Power Flow Analysis)
- Grid State Identification
- Intelligent Grid Control (Load Forecast)



Infrastructure before Project Start:

- $V_{nom}$ = 660 $V_{DC}$
- 22 Unidirectional Substations
- ≈ 50 Trolleybuses
- ≈ 50 Diesel Buses
- Catenary length ≈ 100 km

[1] German Abbreviation for: Battery-Trolleybus

# Simulation: Workflow

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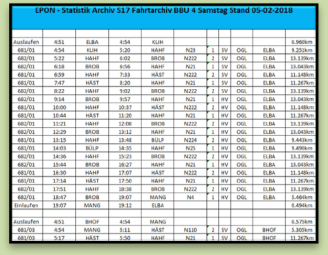
Start → Initialization

## Traffic Network/ Electrical Network

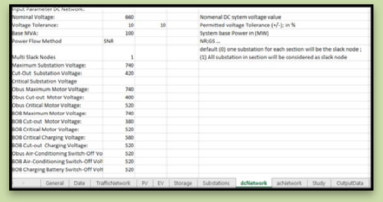

## Bus Timetable



EPON - Statistik Archiv S17 Fahrtarchiv BBU 4 Samstag Stand 05-02-2018

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Auslaufen | 4:51 | ELBA | 4:54 | KLIH | | | | | | 6.960km |
| 681/01 | 4:54 | KLIH | 5:20 | HAHF | N23 | 1 | SV | OGL | ELBA | 9.251km |
| 681/01 | 5:22 | HAHF | 6:02 | BRDB | N222 | 2 | SV | OGL | ELBA | 15.119km |
| 682/01 | 6:18 | BRDB | 6:56 | HAHF | N21 | 1 | SV | OGL | ELBA | 15.041km |
| 681/01 | 6:39 | HAHF | 7:33 | HAST | N222 | 2 | SV | OGL | ELBA | 11.148km |
| 681/01 | 7:47 | HAST | 8:20 | HAHF | N21 | 1 | SV | OGL | ELBA | 11.267km |
| 682/01 | 8:22 | HAHF | 9:02 | BRDB | N222 | 2 | SV | OGL | ELBA | 15.119km |
| 682/01 | 9:14 | BRDB | 9:57 | HAHF | N21 | 1 | HV | OGL | ELBA | 15.041km |
| 681/01 | 10:00 | HAHF | 10:37 | HAST | N222 | 2 | HV | OGL | ELBA | 11.148km |
| 681/01 | 10:44 | HAST | 11:26 | HAHF | N21 | 1 | HV | OGL | ELBA | 11.267km |
| 682/01 | 11:21 | HAHF | 12:08 | BRDB | N222 | 2 | HV | OGL | ELBA | 15.119km |
| 682/01 | 12:29 | BRDB | 13:12 | HAHF | N21 | 1 | HV | OGL | ELBA | 15.041km |
| 681/01 | 13:15 | HAHF | 13:48 | BULP | N224 | 2 | HV | OGL | ELBA | 9.441km |
| 681/01 | 14:03 | BULP | 14:35 | HAHF | N25 | 1 | HV | OGL | ELBA | 9.490km |
| 682/01 | 14:36 | HAHF | 15:23 | BRDB | N222 | 2 | HV | OGL | ELBA | 15.119km |
| 682/01 | 15:44 | BRDB | 16:27 | HAHF | N21 | 1 | HV | OGL | ELBA | 15.041km |
| 681/01 | 16:30 | HAHF | 17:07 | HAST | N222 | 2 | HV | OGL | ELBA | 11.148km |
| 681/01 | 17:14 | HAST | 17:56 | HAHF | N21 | 1 | HV | OGL | ELBA | 11.267km |
| 682/01 | 17:51 | HAHF | 18:38 | BRDB | N222 | 2 | HV | OGL | ELBA | 15.119km |
| 682/01 | 18:47 | BRDB | 19:07 | MANG | N4 | 1 | HV | OGL | ELBA | 5.466km |
| Einlaufen | 19:07 | MANG | 19:12 | ELBA | | | | | | 0.494km |
| | | | | | | | | | | |
| Auslaufen | 4:51 | BHOF | 4:54 | MANG | | | | | | 6.579km |
| 681/03 | 4:54 | MANG | 5:11 | HAST | N110 | 2 | SV | OGL | BHOF | 1.303km |
| 681/03 | 5:17 | HAST | 5:50 | HAHF | N21 | 1 | SV | OGL | BHOF | 11.267km |

## Input Parameters



| | | | |
|---|---|---|---|
| Input Parameters DC Network: | | | |
| Nominal Voltage: | 660 | | Nomenal DC system voltage value |
| Voltage Tolerance: | 10 | 10 | Permitted voltage Tolerance (+/-) in % |
| Base MVA: | 100 | | System base Power in (MW) |
| Power Flow Method | SNR | | NR,GS ... |
| | | | default (0) one substation for each section will be the slack node ; (1) All substation in section will be considered as slack node |
| Multi Slack Nodes | 1 | | |
| Maximum Substation Voltage: | 740 | | |
| Cut-Out Substation Voltage: | 420 | | |
| Critical Substation Voltage | | | |
| Obus Maximum Motor Voltage: | 740 | | |
| Obus Cut-out Motor Voltage: | 400 | | |
| Obus Critical Motor Voltage: | 520 | | |
| BOB Maximum Motor Voltage: | 740 | | |
| BOB Cut-out Motor Voltage: | 380 | | |
| BOB Critical Motor Voltage: | 530 | | |
| BOB Critical Charging Voltage: | 340 | | |
| BOB Cut-out Charging Voltage: | 520 | | |
| Obus Air-Conditionning Switch-Off Vol | 520 | | |
| BOB Air-Conditionning Switch-Off Volt | 530 | | |
| BOB Charging Battery Switch-Off Volt | 520 | | |

General | Date | TrafficNetwork | PV | EV | Storage | Substations | dcNetwork | acNetwork | Study | OutputData

# Simulation: Workflow

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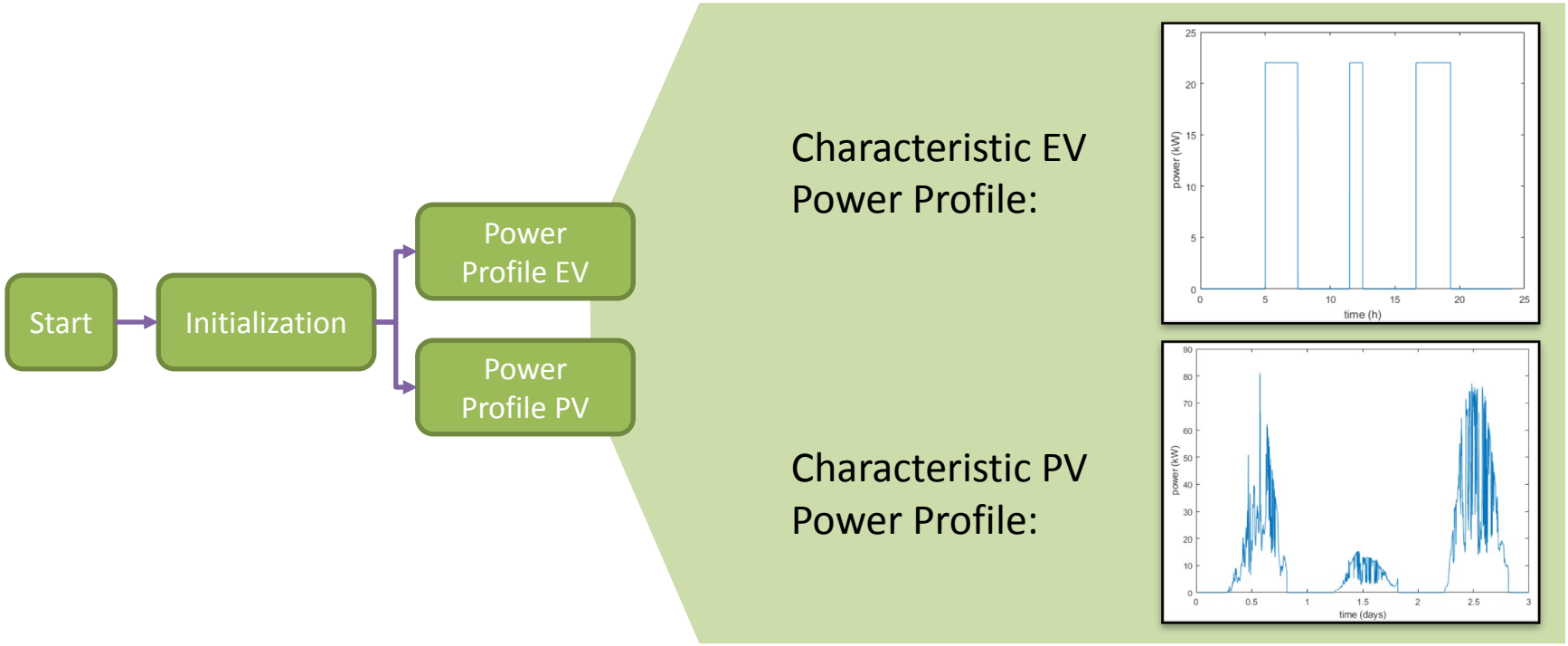

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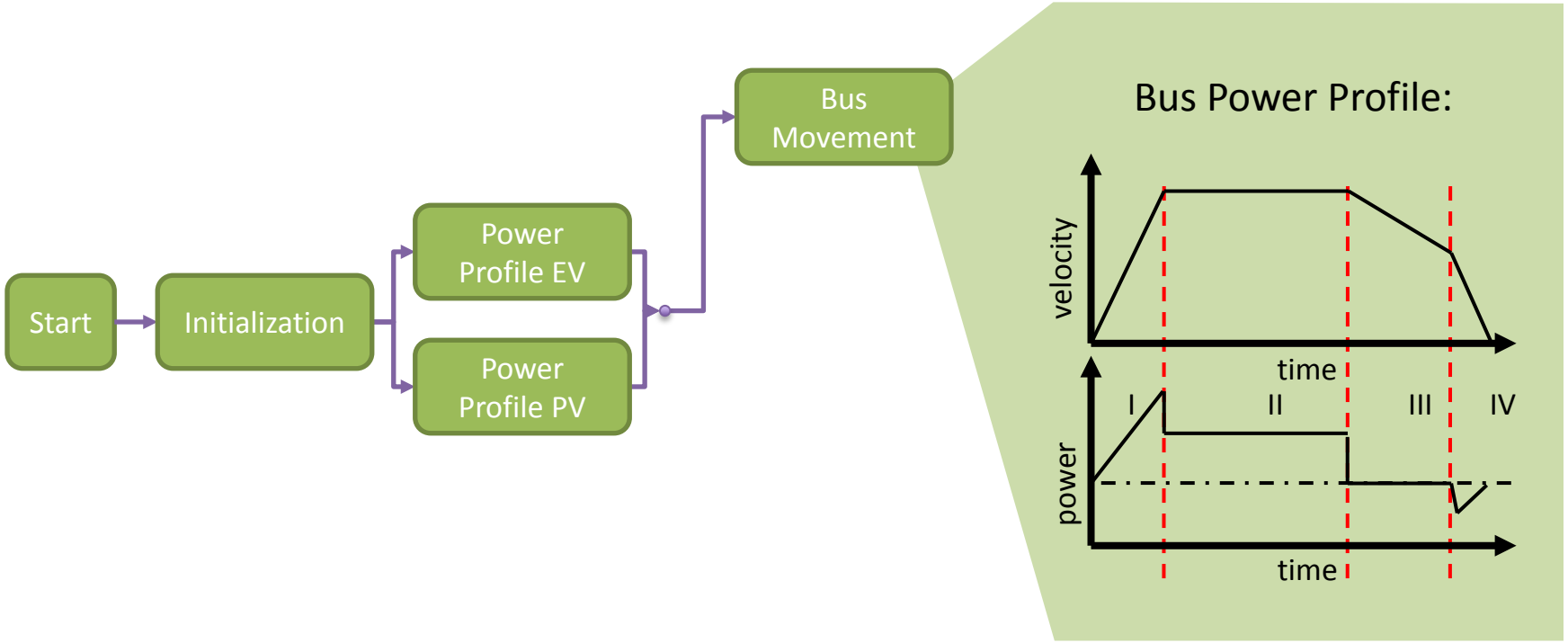

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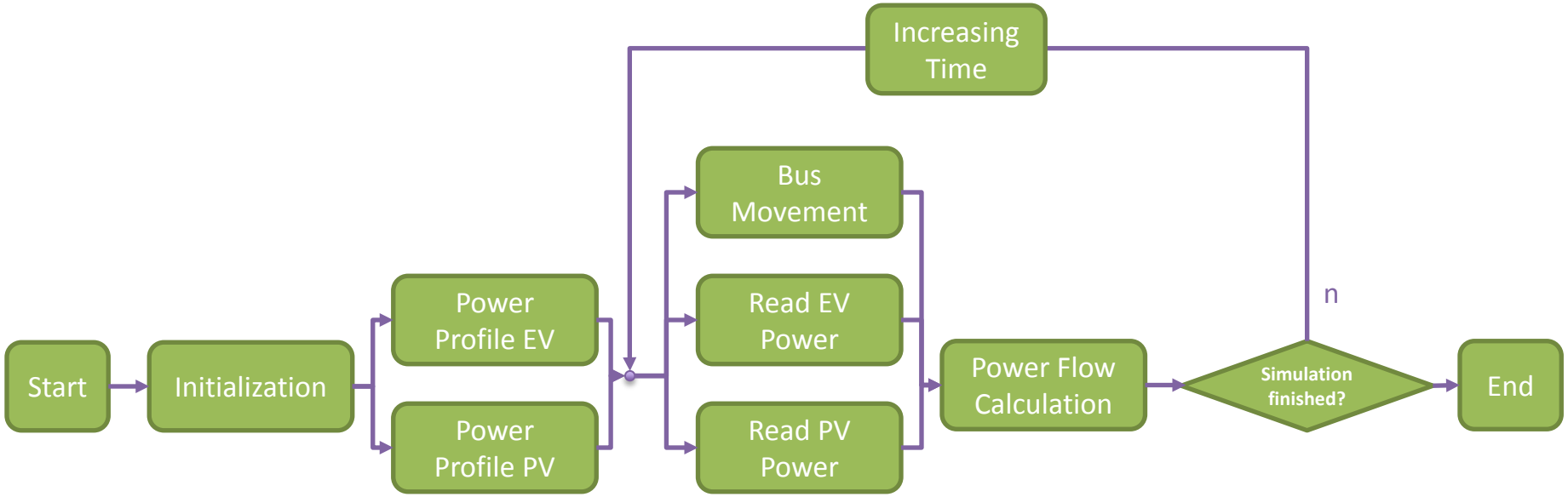

# Simulation: Workflow

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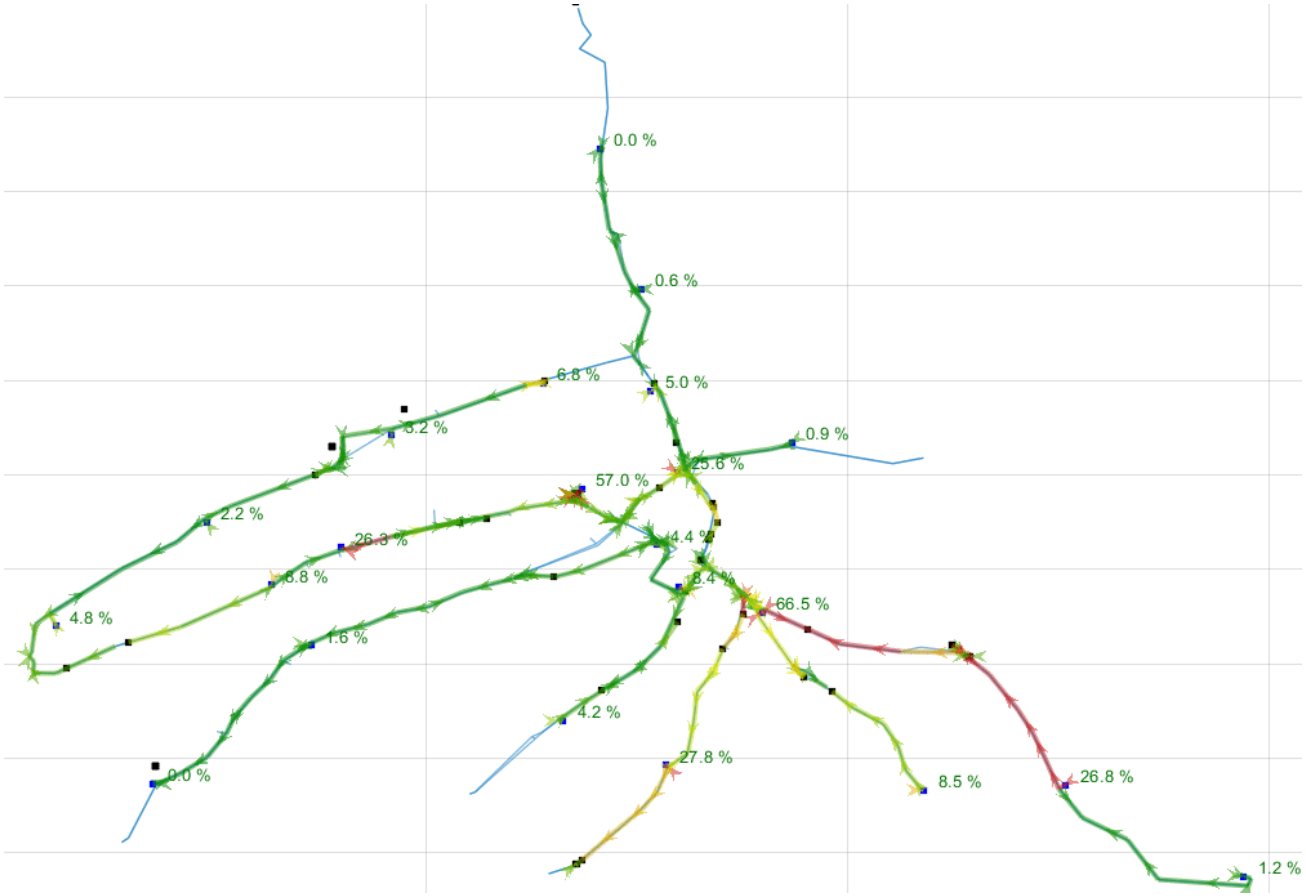
## Current Flow Visualization:



# Simulation: Use-Cases

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- Live-Monitoring and Forecasting for an Intelligent Grid Control
- Optimal Sizing of
  - Photovoltaic Systems
  - Stat. Storage Systems
- Optimal Positioning of
  - EV Charging Stations
  - Photovoltaic Systems
  - Stat. Storage Systems
- Scenario Analyses
  - Present and Future Scenarios
  - Identification of Suitable Bus Lines for BOB Usage

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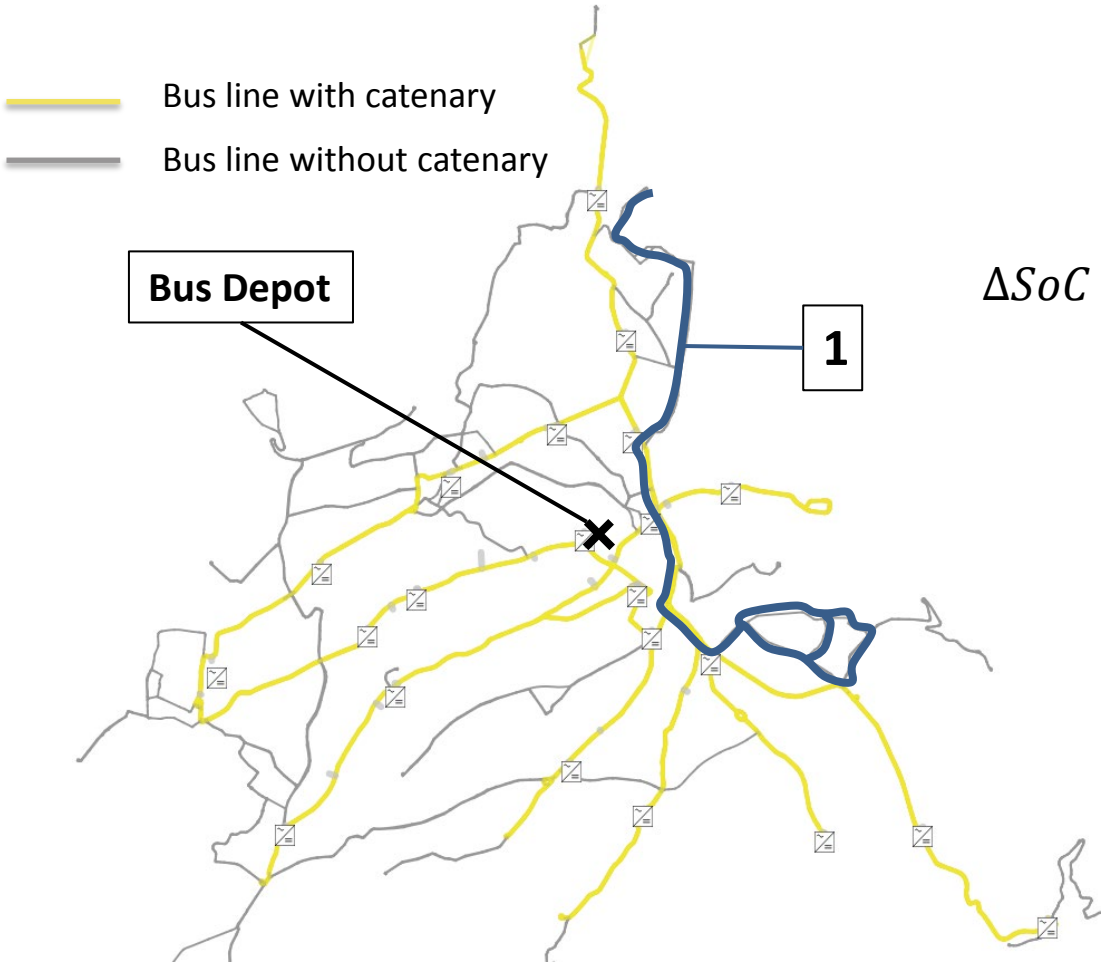
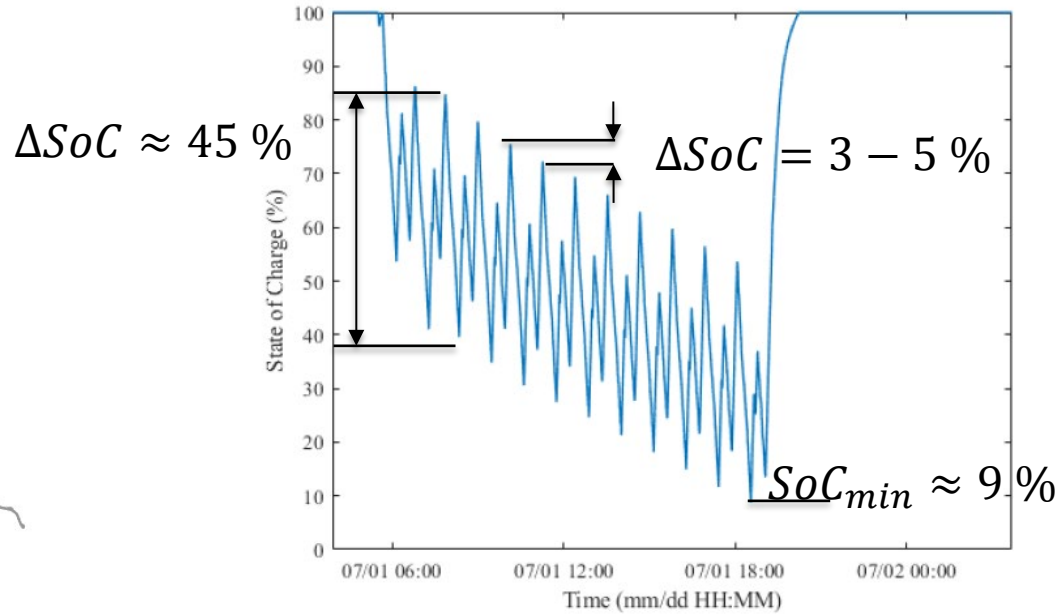
# Identification of Suitable Bus Lines for BOB Usage




- Bus line 695:




- Charging Point will be installed at Terminal Stop
- Suitable for BOB Usage

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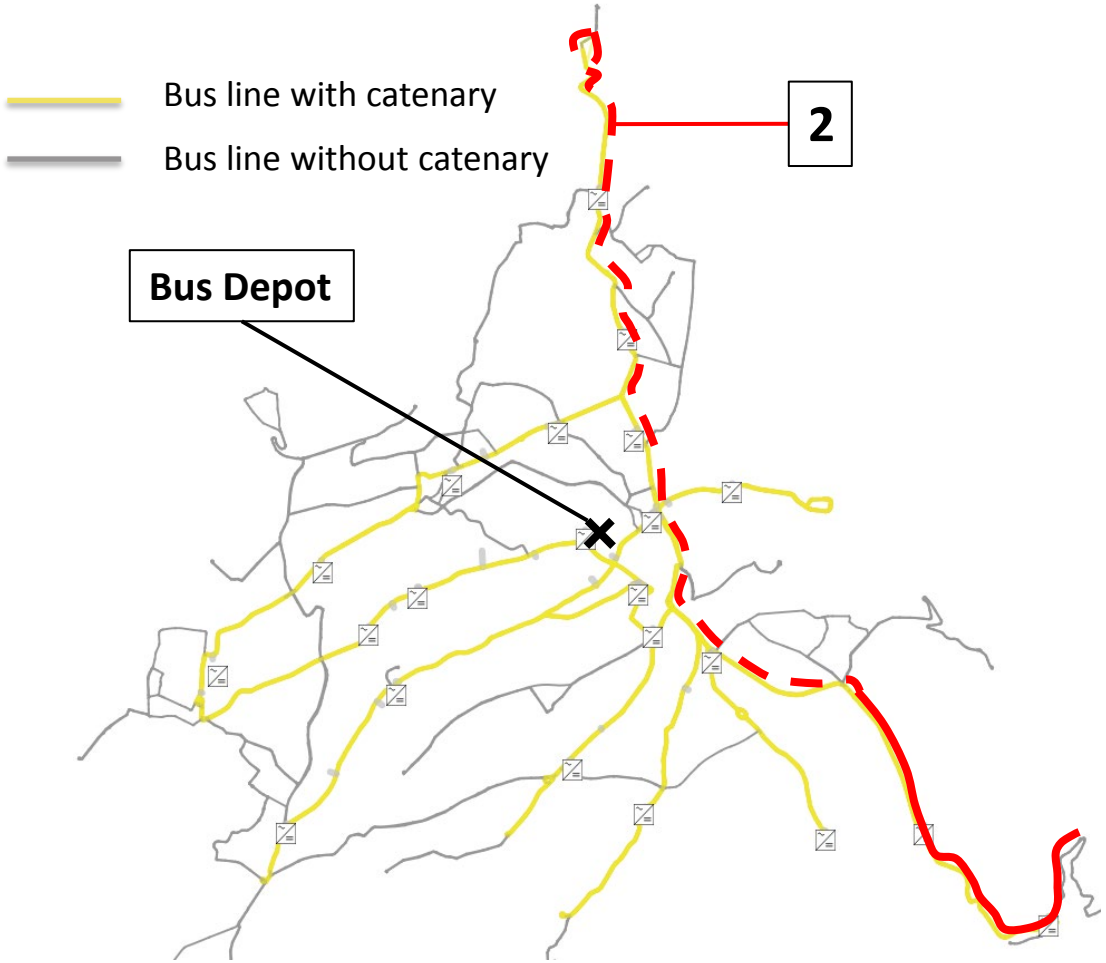
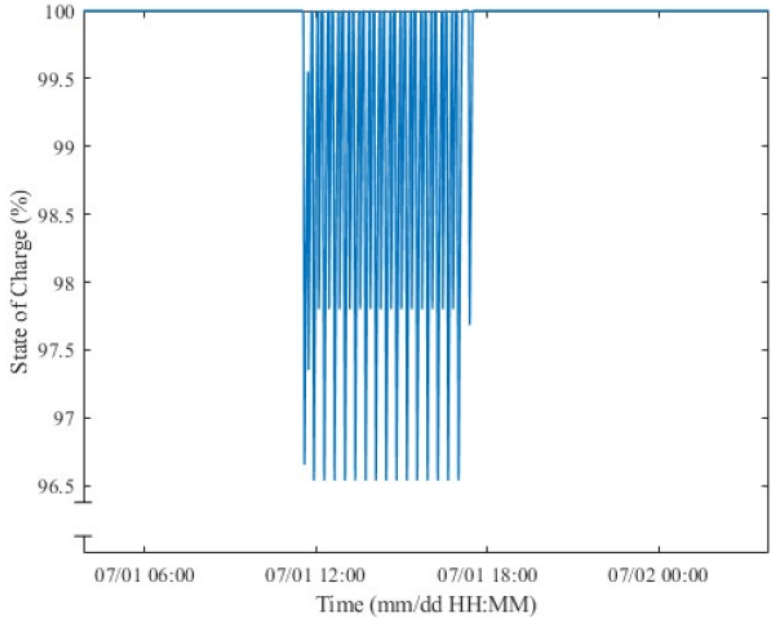
# Identification of Suitable Bus Lines for BOB Usage




- Bus line 683:




- Actually a Trolleybus Line
- Suitable for BOB Usage

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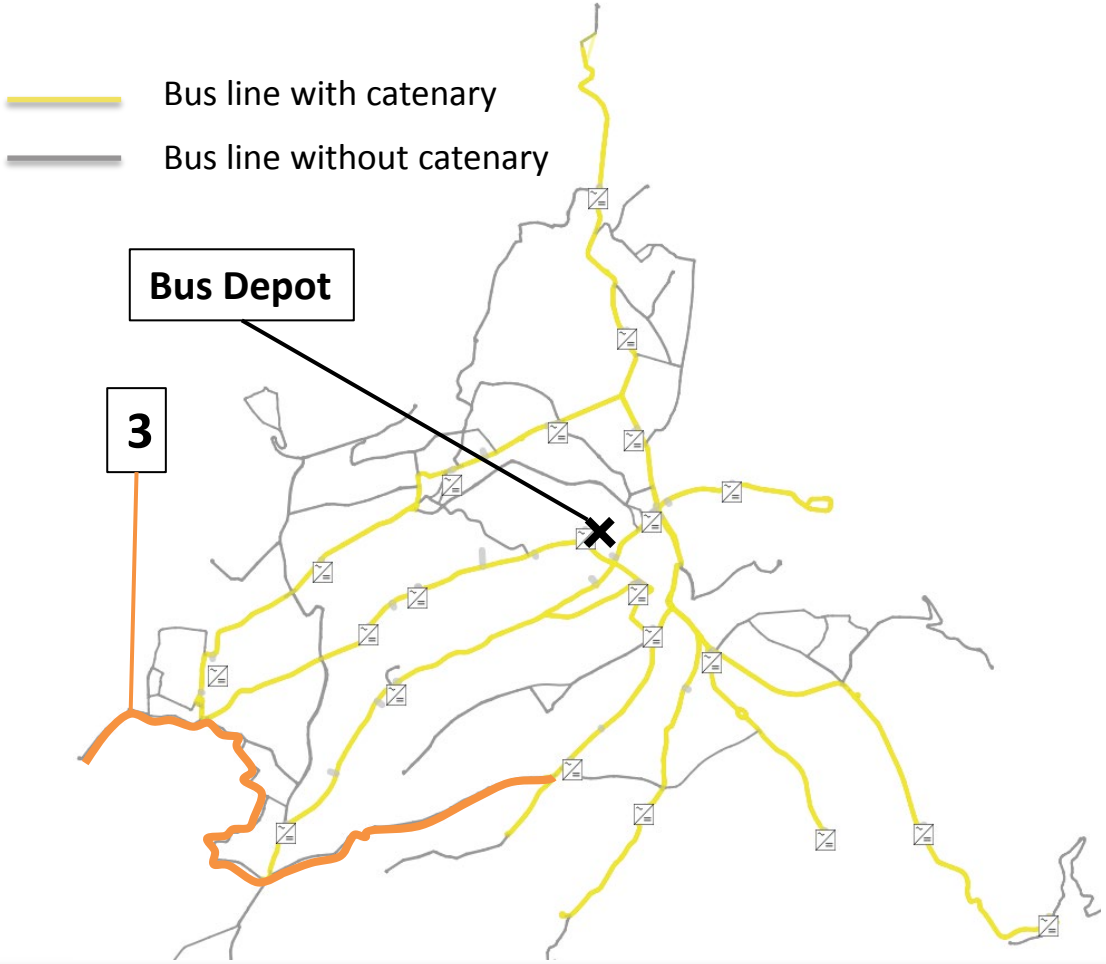
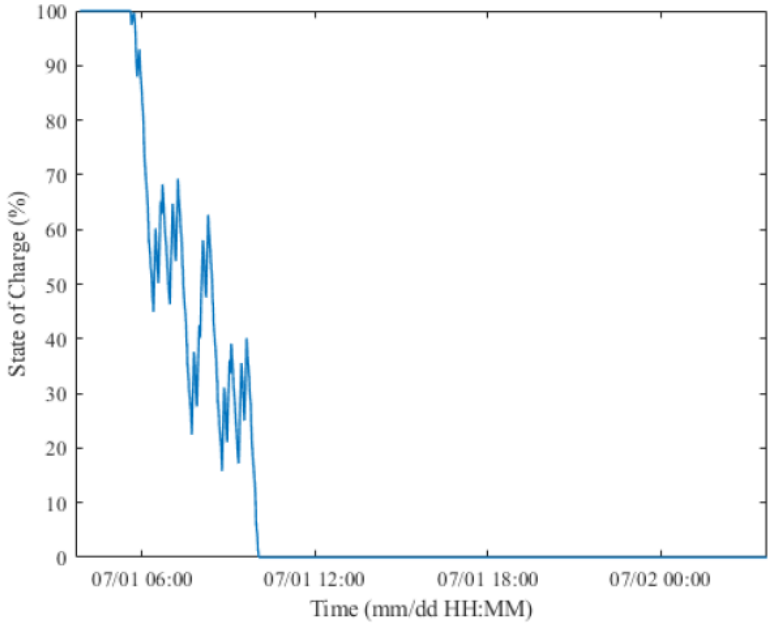
# Identification of Suitable Bus Lines for BOB Usage




- Bus lines 698 & 692:




- Increased Waiting Times under the Catenary, Installation of a Charging Point or Restructuring of the Bus Lines necessary
- Otherwise not suitable for BOB Usage

# Scenario Analyses

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| | | Bus Number | | |
|---|---|---|---|---|
| | | Trolleybuses | BOBs | |
| Scenario | I | 46 | 0 | Only Trolleybuses |
| | II | 46 | 5 | 5 BOBs replacing Diesel Buses* |
| | IIIa | 46 | 69 | All Diesel Buses replaced by BOBs |
| | IIIb | 46 | 43 | Diesel Buses will only be replaced on suitable BOB Routes |

* BOBs will replace Diesel Buses on Bus Line 695 in the Future

# Scenario Analyses

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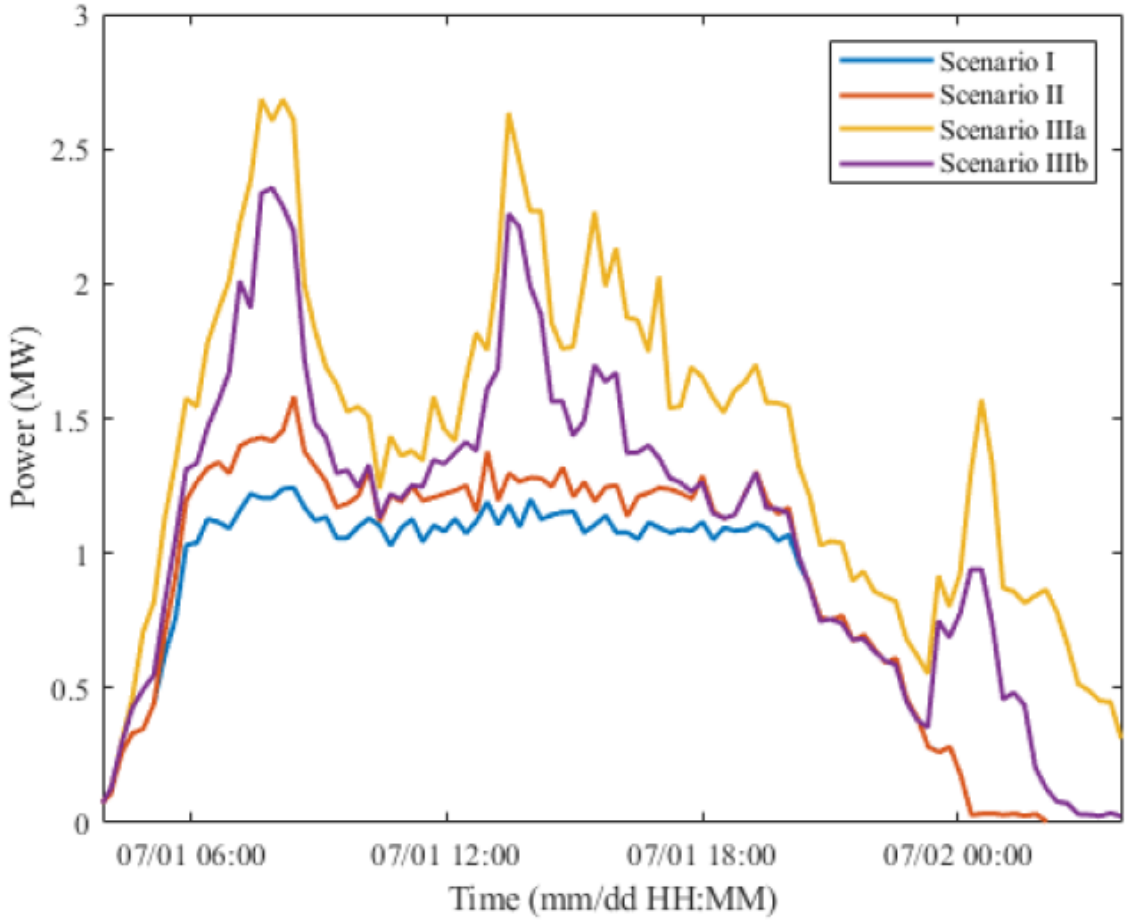


- Extremely high cumulative Power Increase
- Rush-hour Traffic clearly recognizable
- Charging Peak Load in the Evening

# Scenario Analyses

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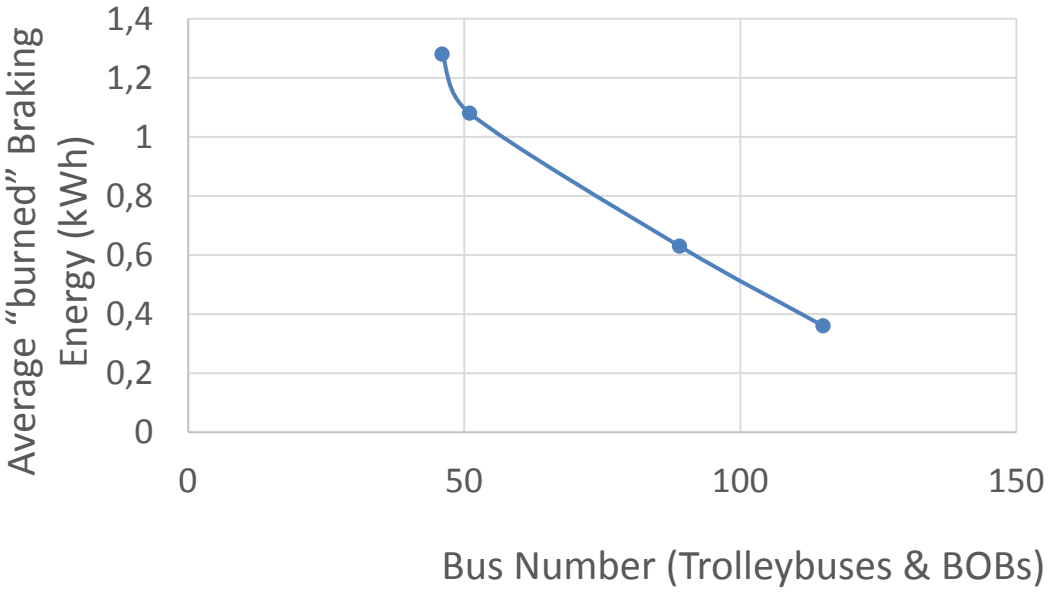
| | | Scenario | | | |
|---|---|---|---|---|---|
| | | *I* | *II* | *IIIa* | *IIIb* |
| Bus Number | Trolleybuses | 46 | 46 | 46 | 46 |
| | BOBs | 0 | 5 | 69 | 43 |
| Summed "burned" Braking Energy (kWh) | | 58.83 | 54.93 | 41.23 | 56.50 |
| Average "burned" Braking Energy (kWh) | | 1.28 | 1.08 | 0.36 | 0.63 |
| Summed System Losses (MWh) | | 1.60 | 1.80 | 3.46 | 2.54 |
| Average System Losses per Bus (kWh) | | 34.69 | 35.39 | 30.07 | 28.58 |

- More regenerative Bus Braking Energy is burned, but the average burned Energy per Bus decreases



# Conclusion & Future Work

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- Future Scenarios show how the Trolleybus System will develop in the Future
- Substations Power Profiles show the Consequence of a worsened Network State
- An Analysis of different Future Scenarios shows how BOB Usage is possible
- Many Diesel Bus Lines do not offer a switch from Diesel Buses to BOBs
- A Restructuring of the Bus Lines is necessary to integrate more BOBs.

# Conclusion & Future Work

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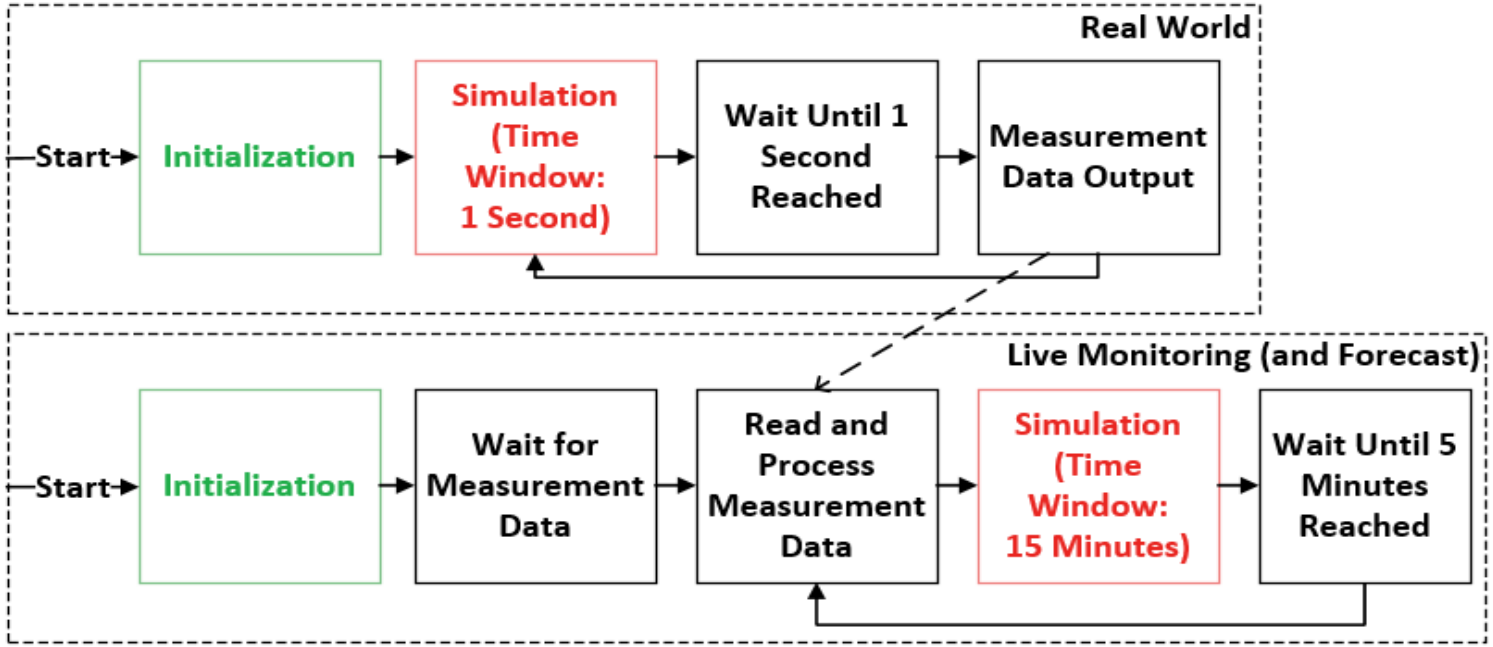
- The Simulation offers the Possibility to perform live Monitoring and Forecasting for the DC Network
- Future Papers will focus on Optimizing the Forecast



# Thank you for your Attention!
# Questions?

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