Advanced functionalities for the future Smart Secondary Substation

Konstantinos Kotsalos ESR 4.4
Efacec & University of Porto
konstantinos.kotsalos@efacec.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Outline

- Introduction
  - Power Flow (PF) Relations
  - PF - scheme
- Towards an OPF scheme
  - Scheme configuration
  - Single-Snapshot Simulation Analysis
- Schedule of operation in LV grid
  - Multi-period framework & Challenges
- Final Remarks

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Power Flow in LV grid

- Radial - weakly meshed
- Unbalanced loads & multi-phase PF
- μG single-phase connection
- R/x ratio $>$ 1

Non-linear + ill conditioned systems

$$g_S(V, S_g) = S_{bus}(V) + S_d - C_g \cdot S_g = 0$$

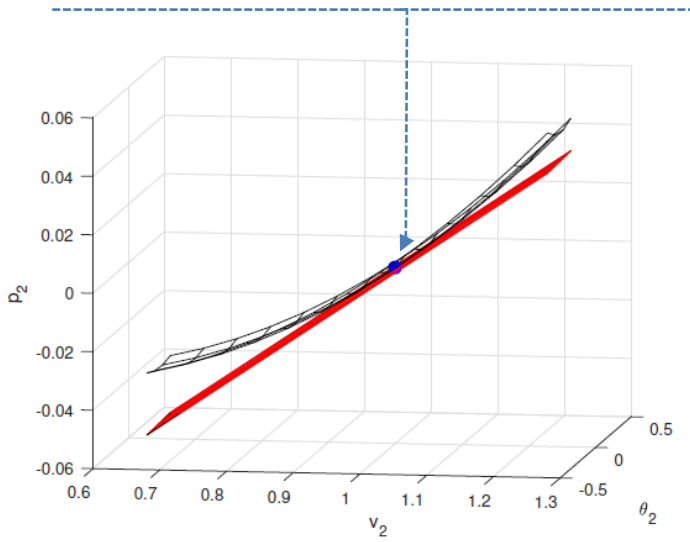
$$P_i^p = |V_i^p| \cdot \sum_{k=1}^{\phi} \sum_{m=1}^{N} |V_k^m| \left[G_{ik}^{pm} \cdot \cos(\theta_{ik}^{pm}) + B_{ik}^{pm} \cdot \sin(\theta_{ik}^{pm}) \right]$$

$$Q_i^p = |V_i^p| \cdot \sum_{k=1}^{\phi} \sum_{m=1}^{N} |V_k^m| \left[G_{ik}^{pm} \cdot \sin(\theta_{ik}^{pm}) - B_{ik}^{pm} \cdot \cos(\theta_{ik}^{pm}) \right]$$

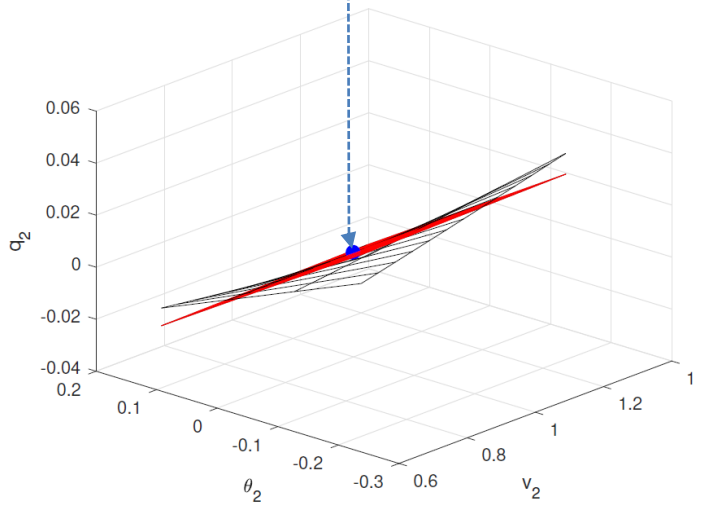
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Power Flow in LV grid

- R/X=3.5 in the simulated case
- Red plane: $\mathcal{L}(\mathcal{v}_0\ ,\vartheta_0)$= $\mathcal{L}(1\ ,0)$ tangent plane



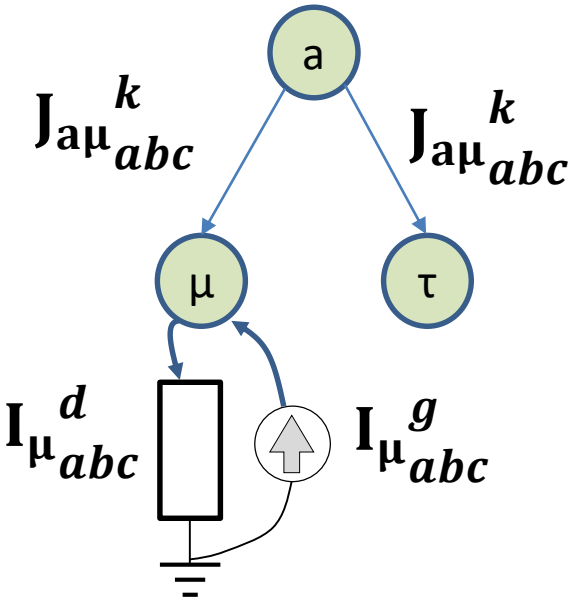
(c) p_2, v_2, θ_2.



(d) q_2, θ_2, v_2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Traverse the network properly

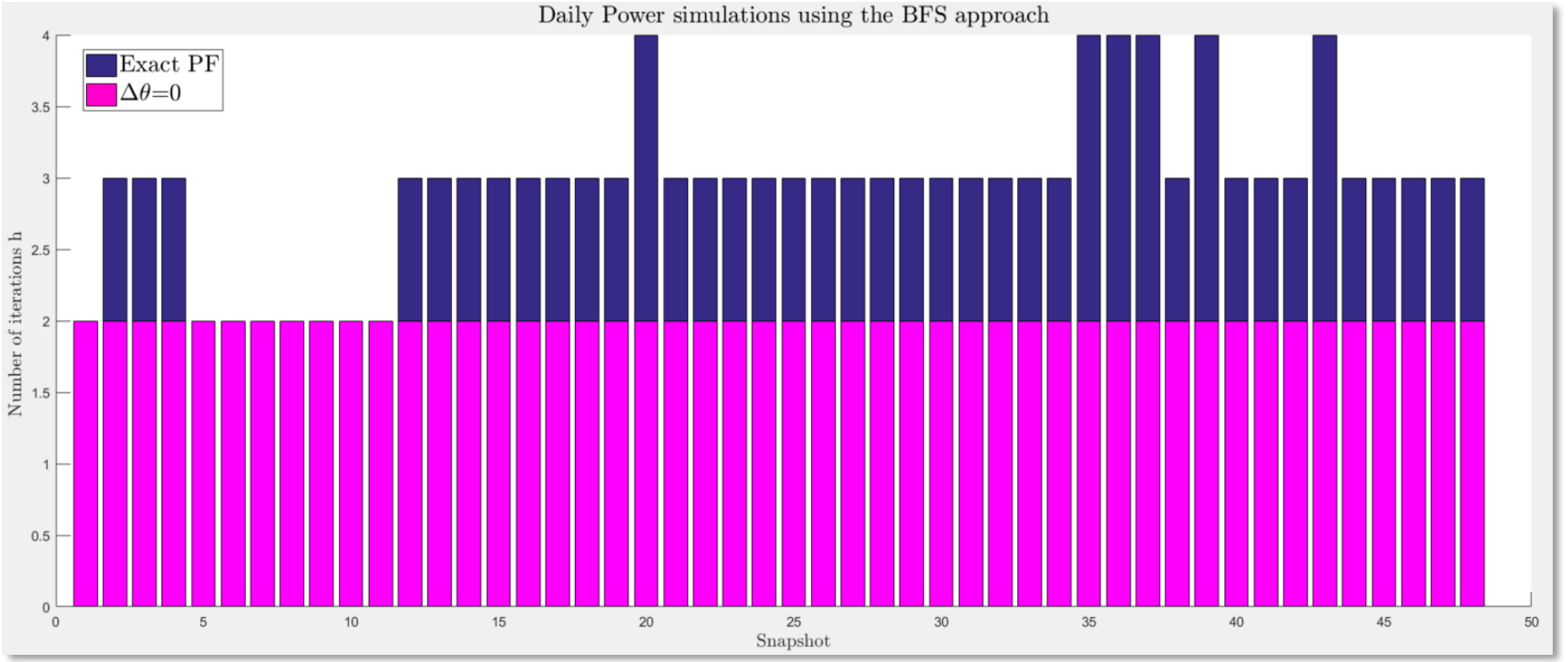


Algorithm 1 BFS description, merely based on [4]

procedure LOAD FEEDER
  Rank nodes, *Node-Order* procedure: Sort m^j
procedure BFS
  initialize $k \leftarrow 1$,
  $V_{j,a}^{(k-1)} = 1\angle 0$, $V_{j,b}^{(k-1)} = 1\angle\frac{2\pi}{3}$, $V_{j,c}^{(k-1)} = 1\angle\frac{-2\pi}{3}$
  do
  Node j Injections : $I_{j,n} = -\sum_{\phi\in\Phi}\left[y_{j,nn}I_{j,\phi}\right]$,
  $I_{j,abc}^{(k)} = \left(\frac{S_{j,abc}}{V_{j,abc}}\right)^{(k-1)^*} - \text{diag}(Y_{j,abc}^{\text{shunt}})\cdot V_{j,abc}^{(k-1)}$
  Backward Sweep- Current Calculation:
  $J_{abc,n}^{(k)} = -I_{j,abcn}^{(k)} + \sum_{m\in M} J_{m_{abc}^{j}}^{(k)}$
  Forward Sweep Calculation:
  $V_{abc,n}^{(k+1)} = V_{abc,n}^{(k)} - [Z_\ell]\cdot J_{abc,n}^{(k)}$
  $k \leftarrow k+1$
  while max $\left(|V_j^{(k)}| - |V_j^{(k-1)}|\right) \geq \epsilon_t$
  return $J_{j,abcn}, V_{j,abcn}, j \in \mathcal{N}$

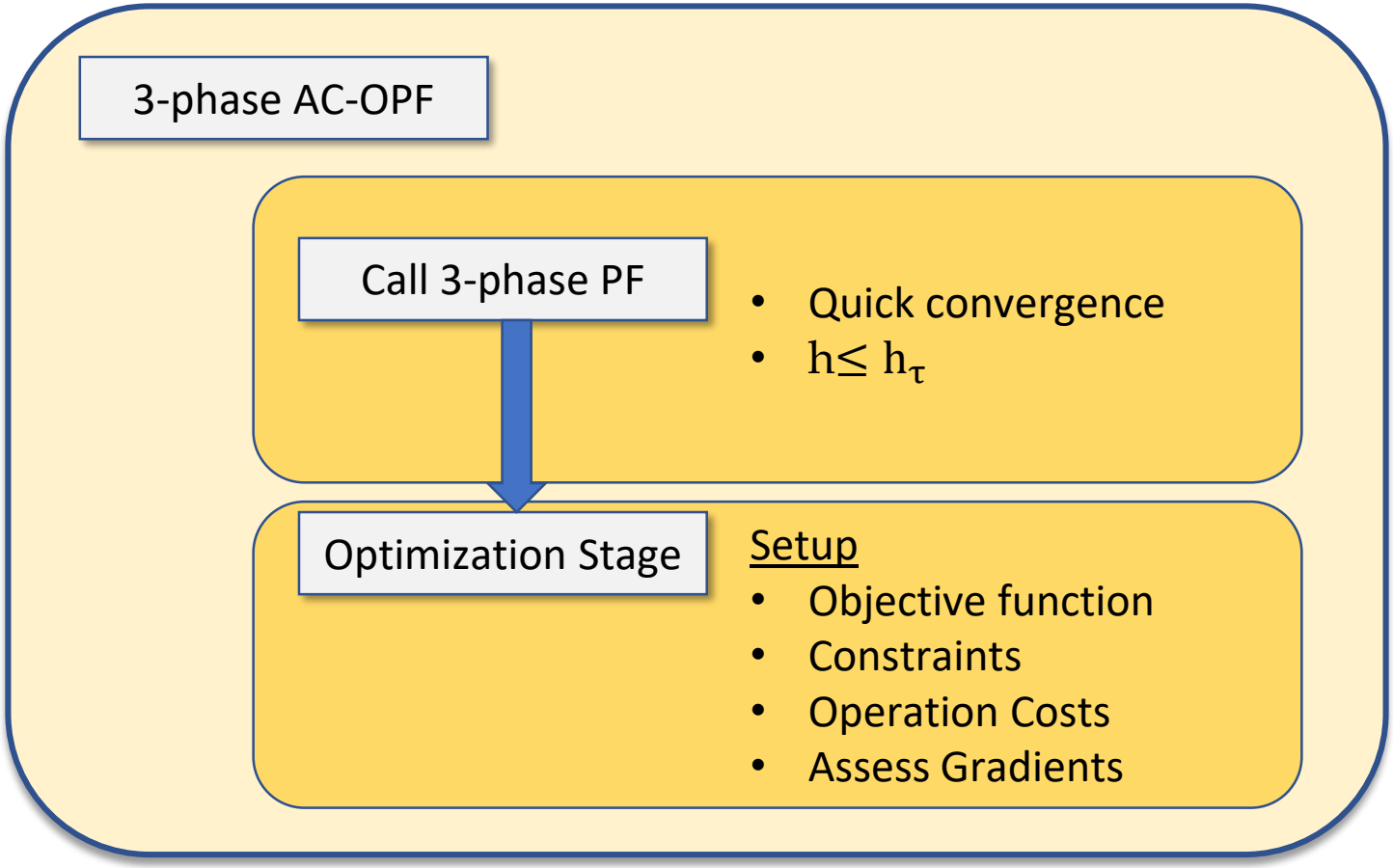
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Backward-Forward Sweep (BFS) Convergence



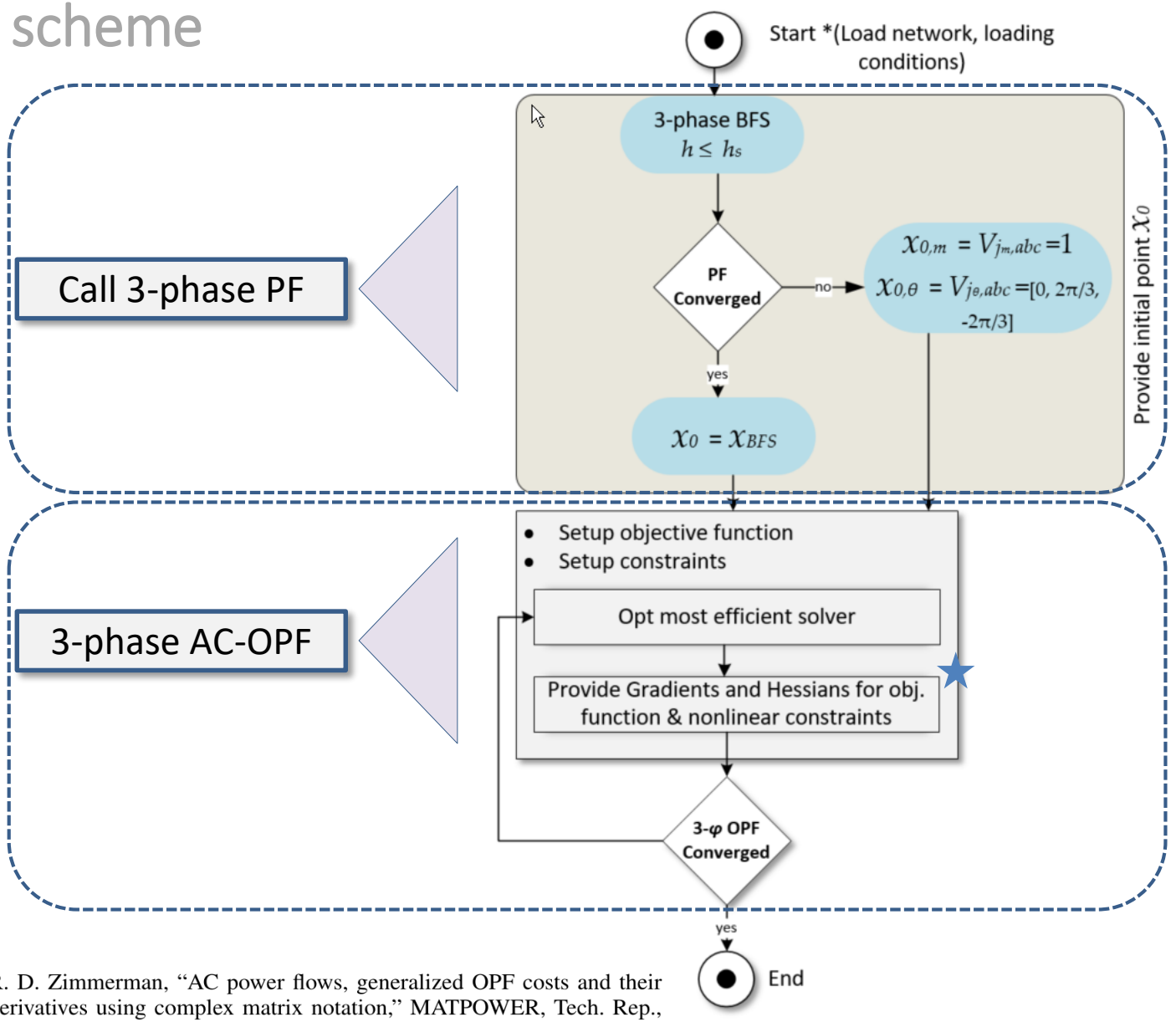
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Towards an OPF scheme



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

3-phase OPF scheme

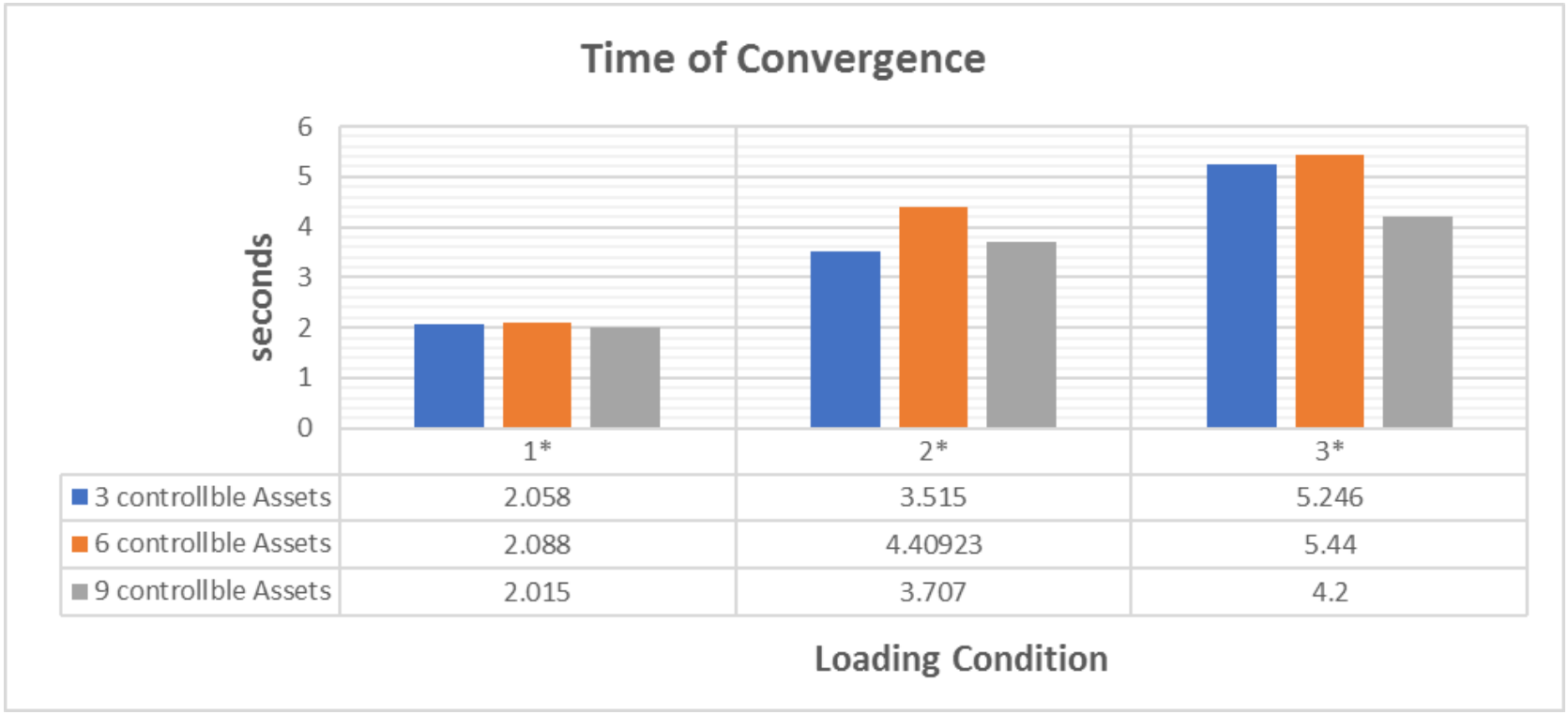


Objective?

★ R. D. Zimmerman, "AC power flows, generalized OPF costs and their derivatives using complex matrix notation," MATPOWER, Tech. Rep., 2010.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

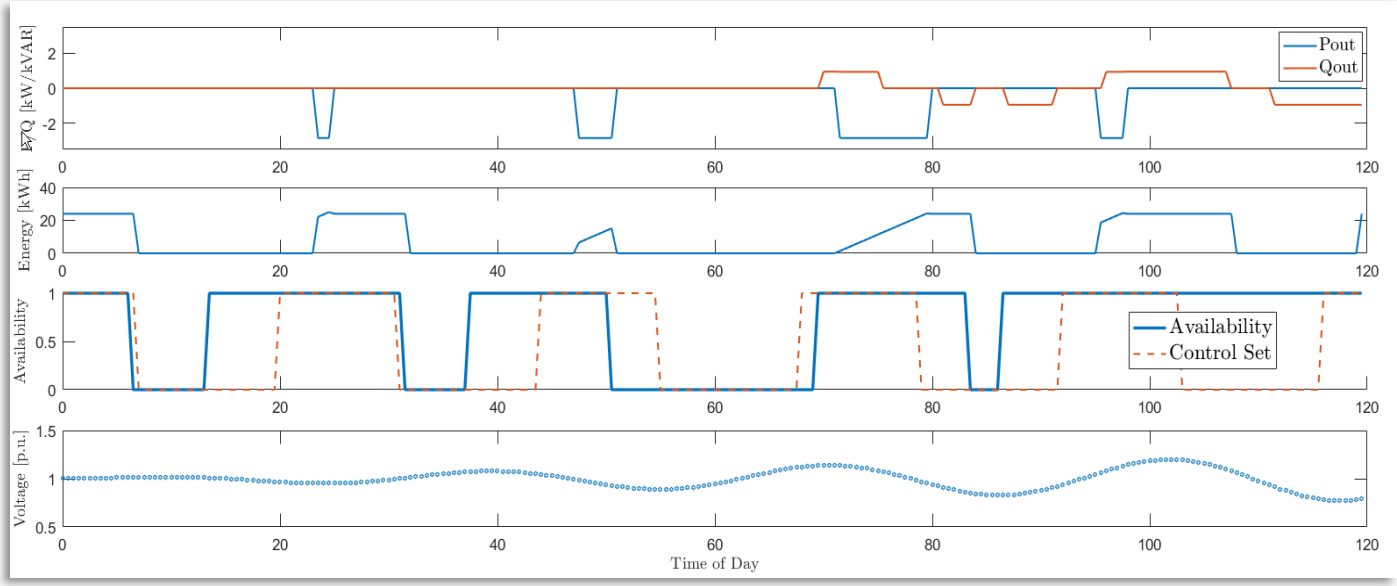
Single-Snapshot Simulation Analysis



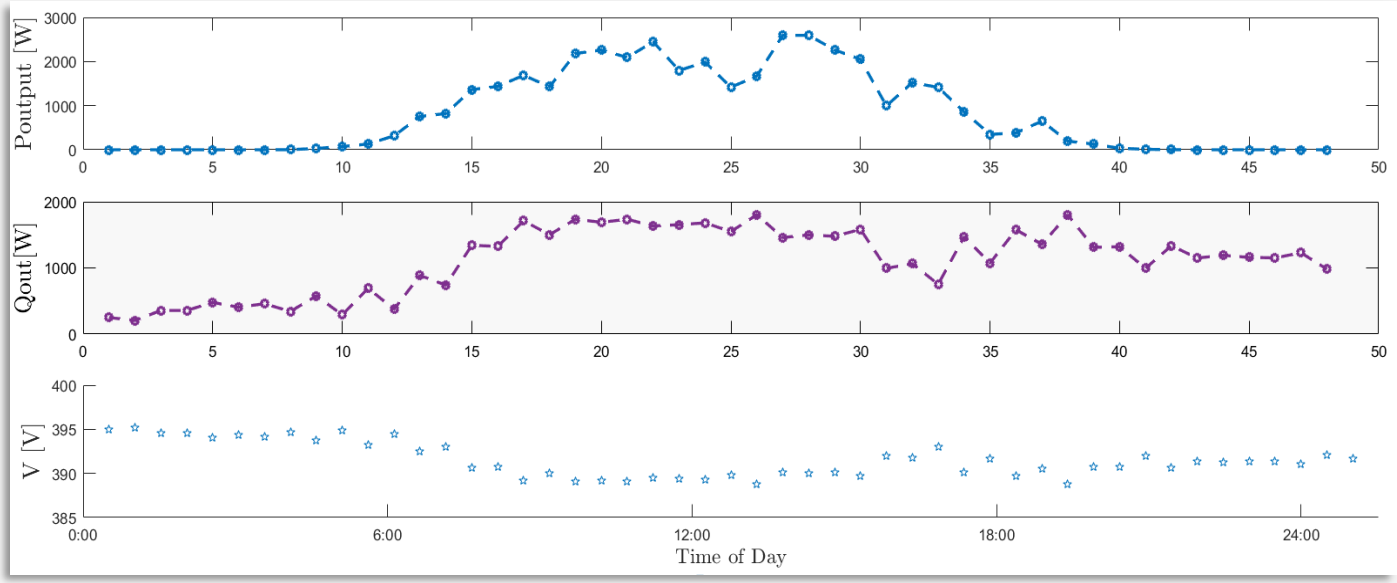
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

DER Model constraints

BSS/EV



µG



- Multi-period scheme in OPF based scheme
  - Inter-temporal constraint couplings
  - Computational complexity matters
  - Integer control variables
  - Approximative relations

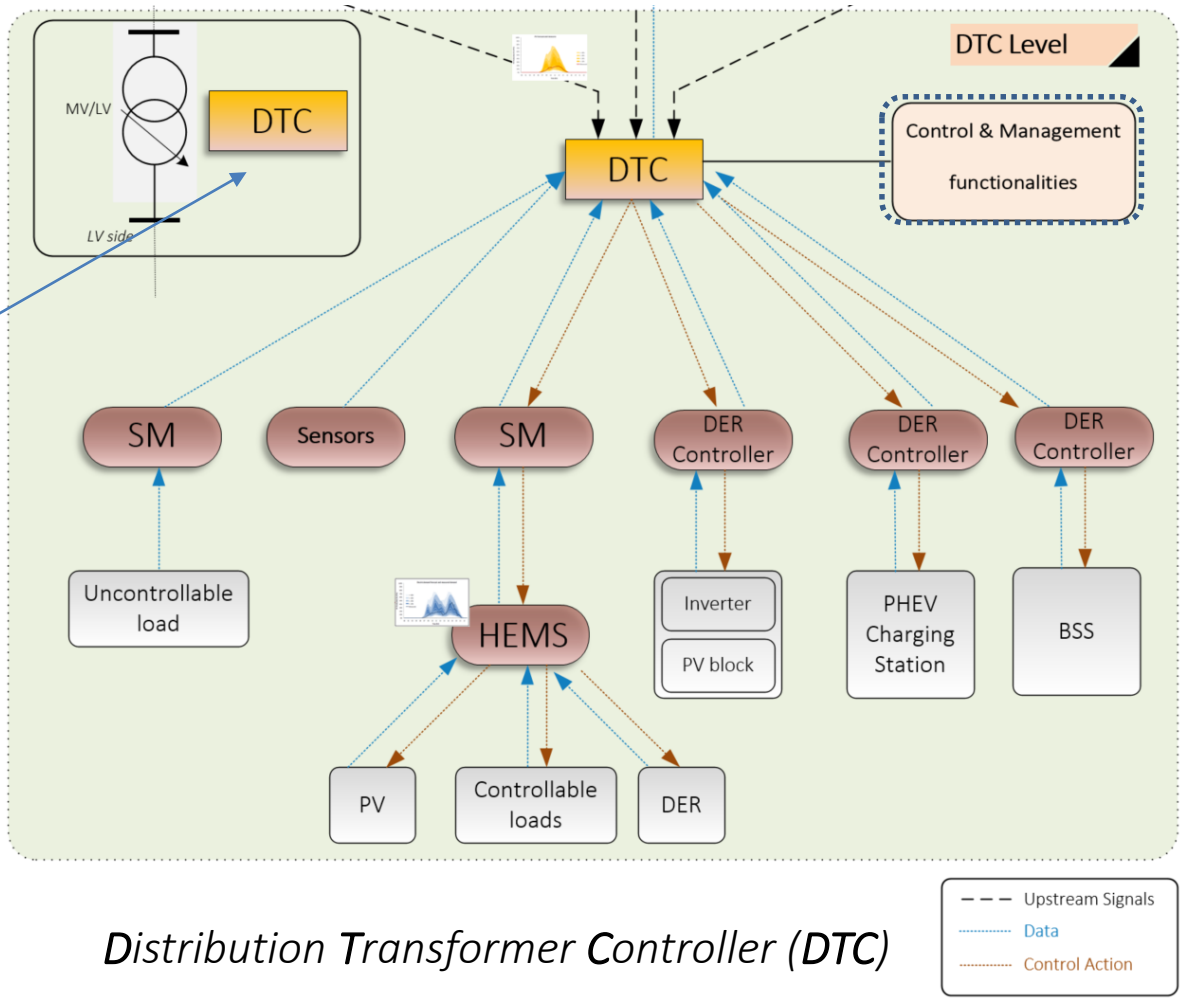
$$\min_{u} \sum_{t=1}^{H_z} C_{obj}(x_t, u_t)$$

- Exact AC-OPF or Approximative? *min($\|x_{opt} - y_f\|$)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Schedule of operation in LV grid

- Where does the scheme fit?



*Distribution Transformer Controller (**DTC**)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Final remarks

- An exact 3-phase AC-OPF is implemented
  - The tool is being extended in multi-period AC-OPF
  - Control & management functionalities to provide optimized technical & cost-efficient operation.
  - Optimal allocation of DER flexibility resources.
- Day-ahead (deterministic) tool
  - Add trajectories to trace uncertainties due to flexibilities deviations
- Expand to MINLP
  - i.e. Controllable loads and tap-position.
- Examine the necessity of approximative relations

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Advanced functionalities for the future Smart Secondary Substation

Konstantinos Kotsalos
Efacec & University of Porto
konstantinos.kotsalos@efacec.com

Advisory Team

Dr. Nuno Silva Prof. Helder Leite
Dr. Ismael Miranda

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318