Co-funded by the Horizon 2020 programme of the European Union

UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics

Enhancing Power Quality in Electrical Distribution Systems Using a Smart Charging Architecture

electrific

Ammar Alyousef
University of Passau

Dominik Danner
University of Passau

Friederich Kupzog
Austrian Institute of Technology

Hermann de Meer
University of Passau

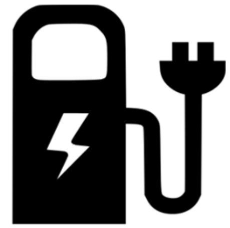
ERIGrid
Connecting European Smart Grid Infrastructures

Computer Networks & Communications
Prof. Hermann de Meer

16th of October 2018

1. Motivation

Approx. 4 kW



Up to 22 kW (Type 2 Connector)

Effect:

- Possible asset overloading due to increasing number of EV charging processes
- Power quality problems, e.g., voltage level, harmonics, flicker, …

Possible Solutions:

- Grid enhancement (transformer, cables)
- Active power management, e.g., BDEW[1] traffic light model [1]
  - Red: Network Phase
  - Yellow: Interaction Phase
  - Green: Market Phase

1 "Bundesverband der Energie- und Wasserwirtschaft"

Agenda

Asset Overloading

- Centralized [2, 3, 4] and decentralized [5, 6, 7, 8] scheduling algorithms
- (Real-time) optimization problem [9]

Power Quality (PQ)

- Design of new hardware [10, 11, 12, 13, 14]
- Local voltage controller [15, 16, 17]

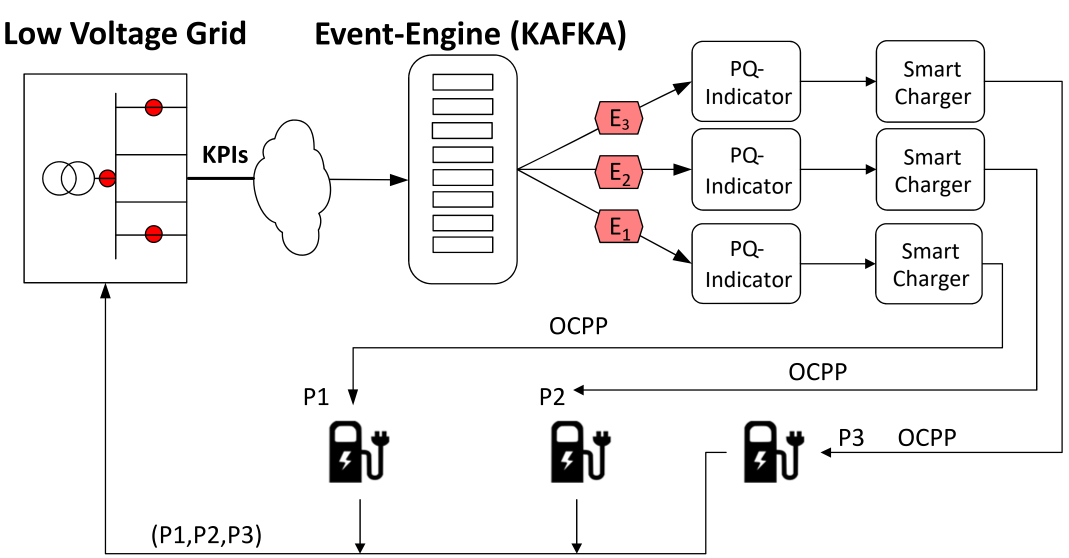
Contribution

- Combination of asset overloading and voltage control in a real-time charging algorithm [18]
- Validation of algorithm using Power Hardware In the Loop (PHIL)

UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics

Design Criteria

- Scalable real-time architecture
- Separation of concerns of the different stakeholders
- Safe test and deployment in real-word environment



P1, P2, P3: Power of the charging station

KPI: Key Performance Indicator of the power grid, e.g. voltage

E1, E2, E3: Event from the power grid

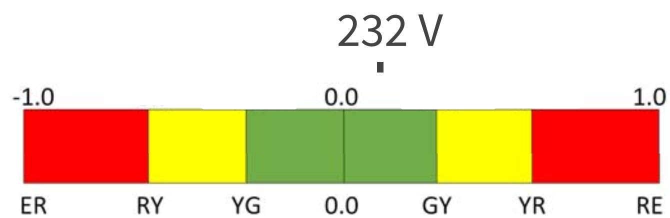
OCPP: Open Charge Point Protocol 1.6+

3.1. PQ-Indicator (1)

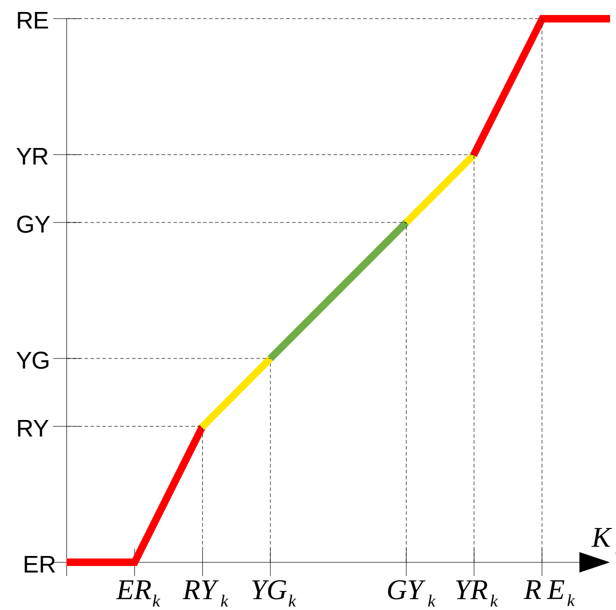
Input: Power Grid KPIs

Output: *PQ-Indic* ∈ [-1,+1]

- *PQ-Indic* defined using traffic light model
  - Green (G): Grid state is stable
  - Yellow (Y): Grid state is non-optimal
  - Red (R): Grid state is critical
- KPI K_k transformation
  - Piece-wise linear interpolation function
  - Thresholds: ER_k, RY_k, YG_k, GY_k, YR_k, RE_k
  - Example: YG_U = 225 V, GY_U = 235 V, …



PQ-Indic to traffic light model mapping

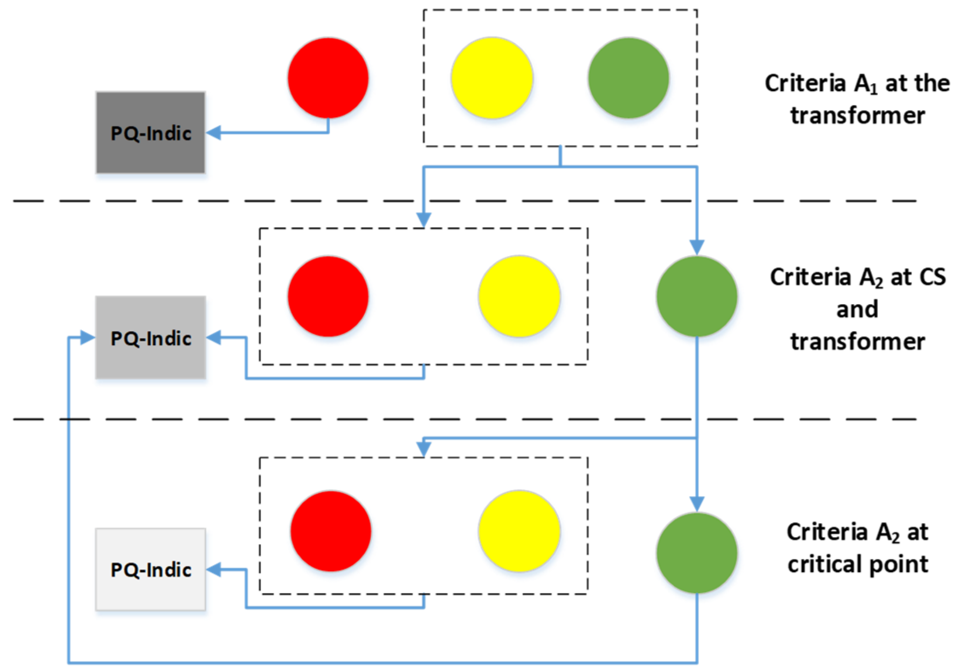


Piece-wise linear interpolation

3.1. PQ-Indicator (2)

Combining different KPIs

- Two criteria
  - A_1: Grid asset overloading
  - A_2: Voltage level
- Different grid locations
  - Transformer
  - Charging Station (CS)
  - Critical points
- Three-layer hierarchical logic



Hierarchical combination logic

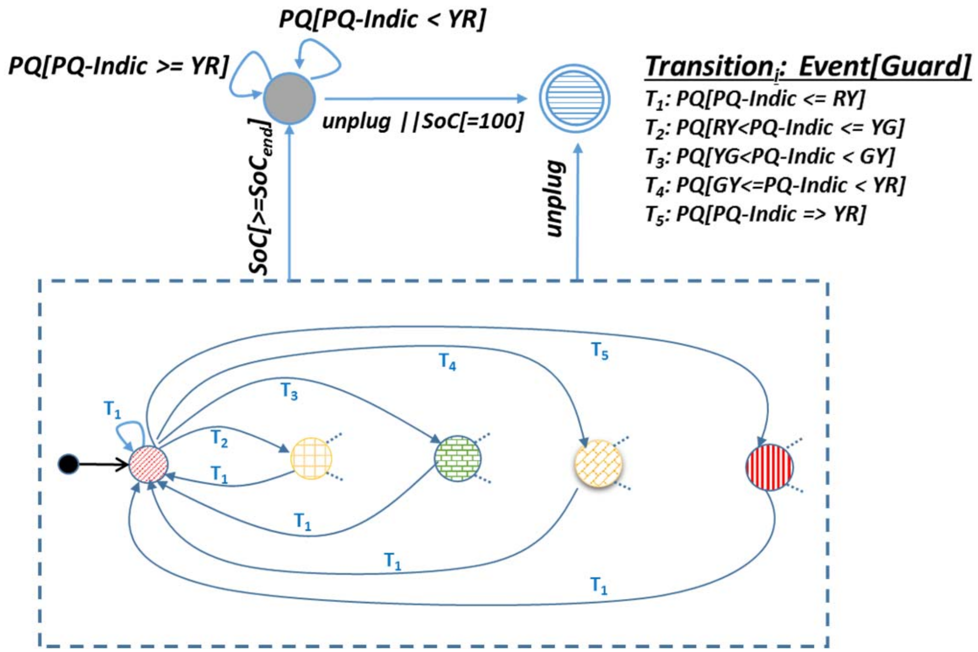
UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics

3.2. Smart Charger

Input: PQ-Indic

Output: Power at the CS

- Finite State Machine (FSM)
  - Seven states
  - Transitions after events, e.g., new PQ-Indic, SoC change, …
- Actions of state transitions based on destination state
  - Low/high red → polynomial increase/decrease
  - Low/high yellow → linear increase/decrease
  - Green → follow the users charging profile
  - Gray (standby) → increase only when critical

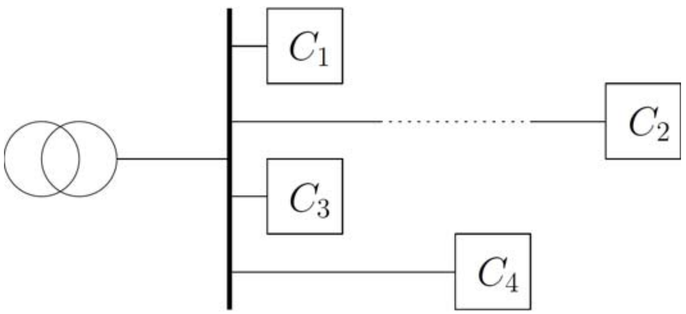


Finite state machine of the smart charger

UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics

Simulation Setup

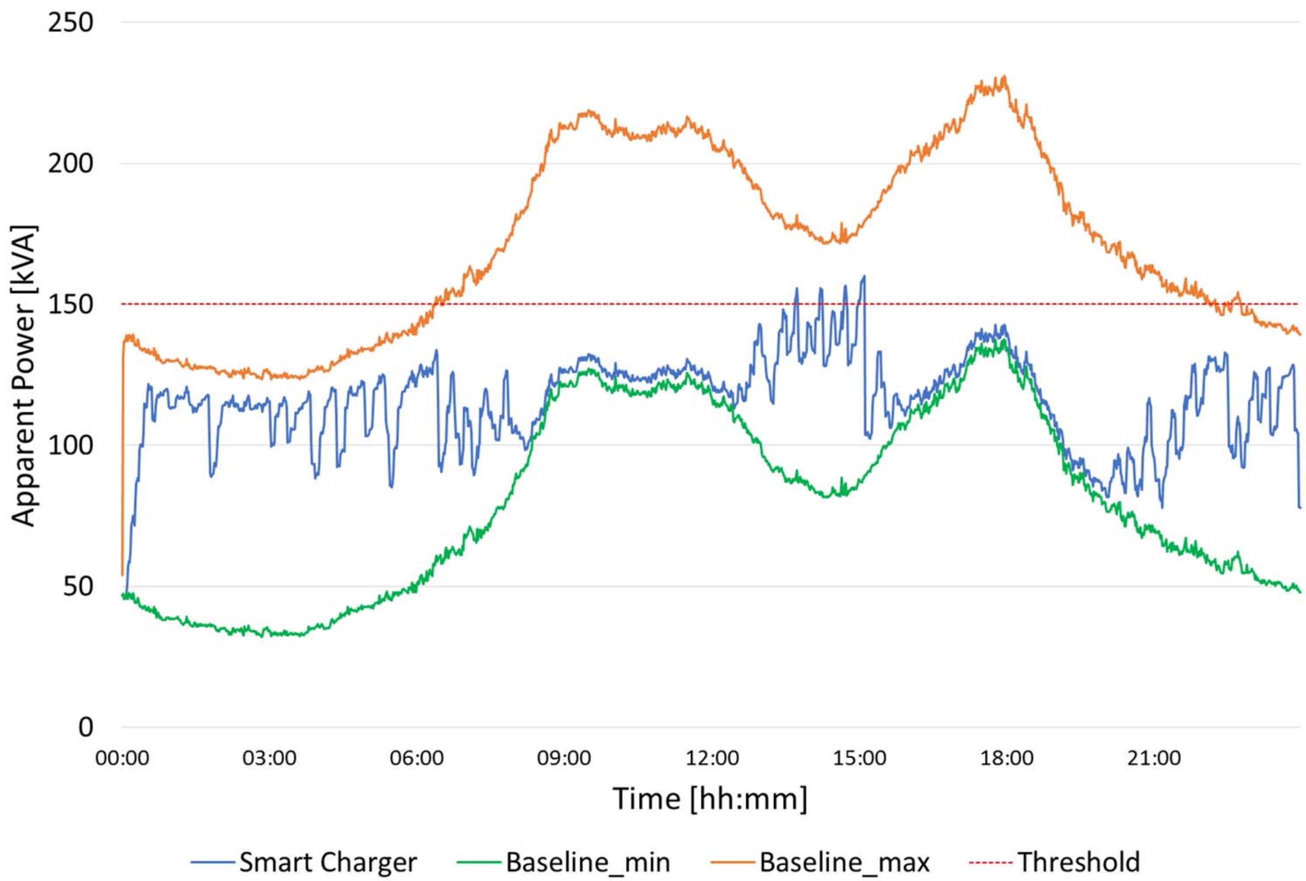
- Real low voltage grid with realistic load profiles
- Four CSs at three different locations
- One minute between FSM transitions
- Baseline scenarios
  - Baseline_min: No charging at all
  - Baseline_max: All CSs charge with 22 kW



Location of the charging stations

4. Evaluation (2)

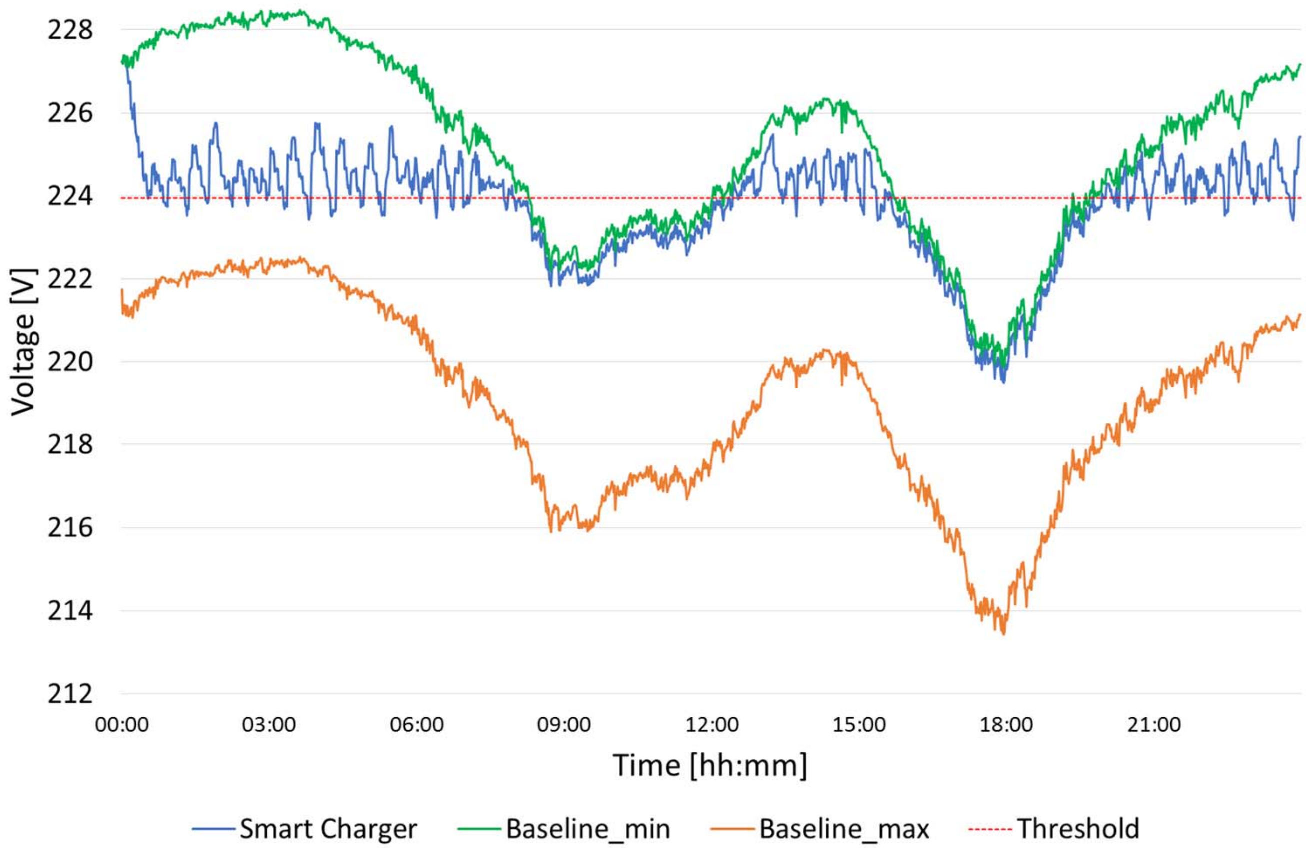
UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics



Apparent power at the transformer

4. Evaluation (3)

UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics



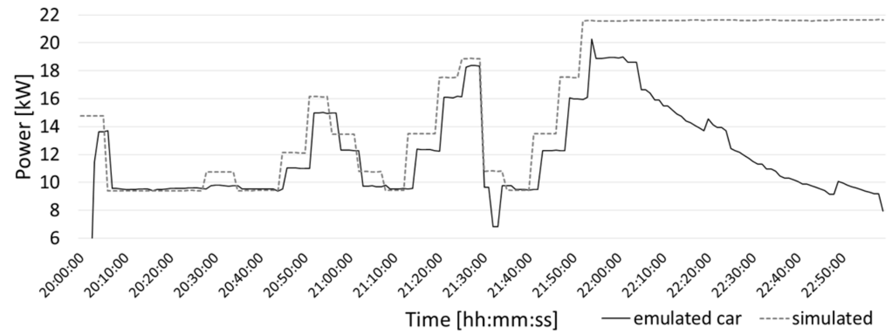
Voltage level at the critical point

UNIVERSITY OF PASSAU
Faculty of Computer Science and Mathematics

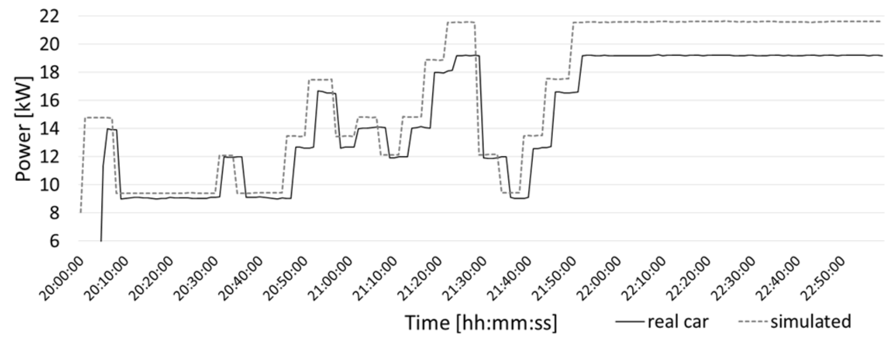
PHIL at *AIT FlexEVLab*

- Emulated electric vehicle via RLC load
- Real electric vehicle via Type 2 CS

- Results
  - Real/emulated electric vehicle with initialization and battery saturation phase
  - Slight impact on the smart charger behavior due to accuracy, reaction time and saturation phase



Emulated EV vs charging signal



Real EV vs charging signal

5. Conclusion and Future Work

- Conclusion
  - Finite state machine appropriate for mitigating asset overloading and power quality issues
  - Real world applicable

- Future Work
  - Perform further evaluations with different timing and field tests
  - Improve fairness among charging stations
  - Included Vehicle-2-Grid

Thank you for your attention!

Questions?

References

[1] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V.: BDEW Roadmap, Realistic Steps for the Implementation of Smart Grids in Germany. Accessed on 12th of Sep. 2018 (2013). https://www.bdew.de/energie/bdew-roadmap-smart-grids/

[2] Lopes, J.A.P., Soares, F.J., Almeida, P.M.R.: Identifying management procedures to deal with connection of electric vehicles in the grid. IEEE Bucharest PowerTech, (2009).

[3] Chung, C., Chynoweth, J., Chu, C., Gadh, R.: Master-slave control scheme in electric vehicle smart charging infrastructure. The Scientific World Journal 2014 (2014)

[4] Deilami, S., Masoum, A.S., Moses, P.S., Masoum, M.A.S.: Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile. IEEE Transactions on Smart Grid, (2011).

[5] Cortés, A., Martínez, S.: A hierarchical algorithm for optimal plug-in electric vehicle charging with usage constraints. Automatica, (2016).

[6] Rivera, J., Goebel, C., Jacobsen, H.-A.: A distributed anytime algorithm for real-time ev charging congestion control. ACM International Conference on Future Energy Systems, (2015).

[7] Alonso, M., Amaris, H., Germain, J., Galan, J.: Optimal charging scheduling of electric vehicles in smart grids by heuristic algorithms. Energies, (2014).

[8] Kong, F., Liu, X., Sun, Z., Wang, Q.: Smart Rate Control and Demand Balancing for Electric Vehicle Charging. ACM/IEEE International Conference on Cyber-Physical Systems (ICCPS), (2016).

[9] Ardakanian, O., Rosenberg, C., Keshav, S.: Distributed control of electric vehicle charging. ACM International Conference on Future Energy Systems, (2013).

[10] Tanaka, T., Sekiya, T., Tanaka, H., Hiraki, E., Okamoto, M.: Smart charger for electric vehicles with power quality compensator on single-phase three-wire distribution feeders. IEEE Energy Conversion Congress and Exposition (ECCE), (2012).

[11] Restrepo, M., Morris, J., Kazerani, M., Cañizares, C.A.: Modeling and testing of a bidirectional smart charger for distribution system ev integration. IEEE Transactions on Smart Grid, (2018).

[12] Vahedi, H., Al-Haddad, K.: A novel multilevel multioutput bidirectional active buck pfc rectifier. IEEE Transactions on Industrial Electronics, (2016).

[13] Zhong, Y., Xia, M., Chiang, H.: Electric vehicle charging station microgrid providing unified power quality conditioner support to local power distribution networks. International Transactions on Electrical Energy Systems, (2017).

[14] Yong, J.Y., Ramachandaramurthy, V.K., Tan, K.M., Mithulananthan, N.: Bi-directional electric vehicle fast charging station with novel reactive power compensation for voltage regulation. International Journal of Electrical Power & Energy Systems, (2015).

[15] Foster, J.M., Trevino, G., Kuss, M., Caramanis, M.C.: Plug-in electric vehicle and voltage support for distributed solar: Theory and application. IEEE Systems Journal, (2013).

[16] Martinenas, S., Knezovic, K., Marinelli, M.: Management of power quality issues in low voltage networks using electric vehicles: Experimental validation. IEEE Transactions on Power Delivery, (2017).

[17] Álvarez, J.N., Knezovic, K., Marinelli, M.: Analysis and comparison of voltage dependent charging strategies for single-phase electric vehicles in an unbalanced danish distribution grid. International Universities Power Engineering Conference (UPEC), (2016).

[18] Alyousef, Ammar, et al. "Enhancing power quality in electrical distribution systems using a smart charging architecture." *Energy Informatics* 1.1 (2018): 28.