Automatic topology identification of weak low voltage networks and load management strategies for micro-mobility applications

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Abstract for the topic: EV1: Ecological Vehicles, d: Two- and three-wheel vehicles

Urban micro-mobility challenge: charging infrastructure and load management

With 55 % of the world's population residing in urban areas in 2018 and a projected rise up to 68% by 2050 [1], the challenge of integrating sustainable mobility solutions into the existing urban infrastructure is gaining worldwide attention. Alternative environmentally friendly urban mobility solutions have been expanding worldwide, as car manufacturers are adding more e-vehicles in their lineup, more strict regulations are favoring electric-mobility, and an ever-increasing number of cities around the world are optimistically experimenting with the concept of micro-mobility. Germany's Federal Ministry for Economic Cooperation and Development (BMZ) [2] expresses that the concepts of urban mobility need to be rethought and, specifically, planned and implemented in a more sustainable, inclusive and integrated manner than has been the case until now. The German Development Cooperation is advocating for cities to move their transport systems towards sustainability in order to become more climate-friendly, healthy, inclusive, safe, prosperous and attractive [2]. With the passage of the Small Electric Vehicles Act (eKFV), e-scooters were declared street-legal in Germany as of 15 June 2019 [3]. In drafting the eKFV, the German government specifically referenced the sustainability of e-scooters, noting their ability to increase urban mobility [3]. As micro-mobility options are emerging as a new trend and popular solution for the last mile within the urban areas, the main challenge beyond improving legislation, expansion of pathways, and safety remains to be the provision of adequate charging infrastructure and load management strategies.

The impact of expansion of electro-mobility is significant for the gird operators, who will need to provide the charging infrastructure, as there is a need to manage line congestion and voltage drops of the energy networks [4]. Networks reinforcement is one solution, however this solution is expensive and typical usage times are short. An alternative is to integrate smart grid control techniques, avoiding relatively larger investments. For this purpose, an energy management system retrofitted to an existing public street lighting network can provide a more economic and reliable solution. An energy management system could also potentially improve the capabilities of the overall system by optimizing the scheduling of loads and power flows.

Smart poles: taking advantage of existing public street lighting infrastructure

Public street lighting networks are conventionally designed for the specific application of illumination during certain dark intervals of the day. This unique behavior provides the opportunity to use the existing power grid infrastructure to provide electricity service to other urban electric applications when the lights are off. Potential hypothetical applications may include: micro-mobility, public USB or environmental sensors, generally speaking a public hub for energy and data.

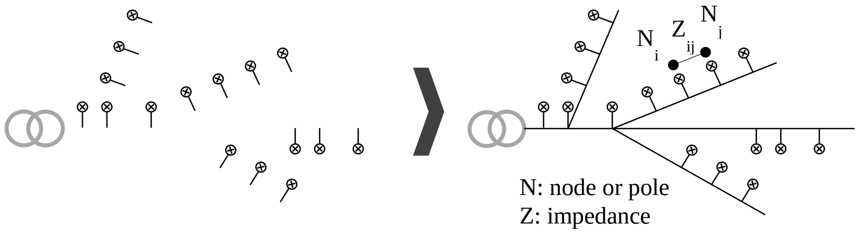
This work was carried out as part of the project "Smart Poles" (Smarte Pfosten), funded by the ZIM program of the Federal Ministry for Economic Affairs and Energy (BMWi, 16KN062820) that aims to retrofit an existing street lighting network, where a smart platform of measurement, computation and communication devices will be developed and installed into the existing poles. An energy management system will be implemented to manage a variety of new energy applications. The new smart layer will enable the existing infrastructure to dynamically manage the power flow beyond its original purpose of illumination. The existing poles are spread relatively homogeneously through the urban areas and conveniently located near the micro-mobility pathways; therefore, they are the ideal candidate to be retrofitted with smart charging stations.

It is important to mention that the focus of the main project is developing a platform to facilitate the integration of electro-mobility applications in existing and future smart city infrastructures. The project consists of three consecutive phases: development of an automatic topology identification algorithm for unknown low voltage weak networks, development and analysis of load management strategies, and the implementation and integration of a smart pole prototype in an energetic community with high penetration of renewable energy.

Keywords: Network Topology, Electro-mobility, Micro-mobility, Energy Management, Smart Grids

Phase 1: automatic topology identification

Growing electricity demand at the urban low voltage weak networks, suggest using the existing network in a managed way for multiple applications, including the fleet of new electric micro-mobility devices. This management relies on detailed knowledge of the network topology, which is defined as the arrangement of nodes and branches of a network and the impedance between them as shown in Figure 1.



1. Unknown Topology

- Node Connections
- Line Impedances
- Phase Distribution

2. Smart Poles Integration
The retrofitted poles enable controllable loads and live measurements.

3. Automatic Topology Identification
The topology (including the Y-Matrix) is identified using a novel method.

Figure 1: topology identification

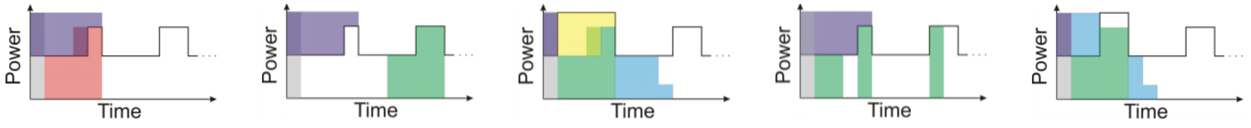
A major challenge in topology identification is having access to accurate network data. The knowledge of phase distribution, topology and/or admittance matrix is often unavailable in low voltage distribution networks. Even if there is such knowledge, it may be outdated or wrong due to newly added or reconfigured partial networks and/or human interaction without information updating [5]. Optimal operations in the distribution network depend on the correct estimation of its bus and node states and its operational topology. However, lines in the network still suffer from limited real time metering that hinders the network operator from learning the true topology [6]. The information of the underlying network topology is useful for efficient integration of distributed renewable generation (PV) and efficient management of controllable loads (electro-mobility) in weak low voltage networks. Knowing the arrangement of loads on the network is essential to make efficient scheduling of connected loads while maintaining the power quality (managing voltage drops and avoid overload of the lines), therefore the topology needs to be identified.

In this work, an automatic method for identification of low voltage networks topology is presented. The first phase involves development of an algorithm for the identification of the topology of a modeled street lighting network. A voltage correlation method is used in this work, which uses the measured voltage data from every node in the network. Dynamic control over loads will provide the opportunity to isolate single loads (on and off) one at a time and measure the voltages at every node throughout the network. Then an algorithm based on series of data manipulation and mathematical calculations is developed to identify the network topology. Using Jenks Natural Break clustering, the topology becomes visible in a matrix illustration of the measured voltage drops. The proposed algorithm was further evaluated and validated by comparing the output graphical representation of topology with the model developed in a Power Factory model. The algorithm is suitable for the identification of single phase low voltage networks topology and can be used as a sub-module in a smart energy management system.

Phase 2: load management strategy development and analysis

The objective of this phase is to evaluate different load management strategies for weak grids with high penetration of electro-mobility applications. The strategies are intended to operate low voltage distribution networks close to their physical and operational limits, which are the current rating of the cables and the voltage level for the safe operation of the applied load. For a safe operation, the power quality with a voltage and frequency stability needs to be provided [7]. According to DIN EN 50160 [8] the grid frequency of 50 Hz has to be kept constant by balancing supply and load at a nominal voltage, which has to be within ±10%. Low voltage distribution networks are dimensioned based on the expected loads and their simultaneity factor. Problems will occur if the loads exceed the original specifications or operation durations. In order to avoid such operation conditions, the grid might be reinforced, or the loads might be managed to avoid the simultaneity of high loads and achieve higher utilization factors.

In this work different load management strategies for the operation of a street lighting network, which has to provide power for electro-mobility, is analyzed on a simulation model [9]. The strategies were tested for two exemplary network topologies, which need to be known to the load management system. One topology is a stab line which is most sensitive for problems with the supplied operation voltage at the last access point. The second topology is a randomly chosen topology. Five different load management strategies were identified and simulated over the selected topologies as illustrated in Figure 2. Maximizing the load acceptance rate (%) and the total delivered energy (MWh) are identified as the two main parameters to be calculated, optimized and compared amongst strategies.



a) Immediate Acceptance (IA)

b) Time Based Shift as Whole (TSW)

c) Time Based Shift & Dispatching for All Remaining Loads (TSD)

d) Time based Shift and Split (TSS)

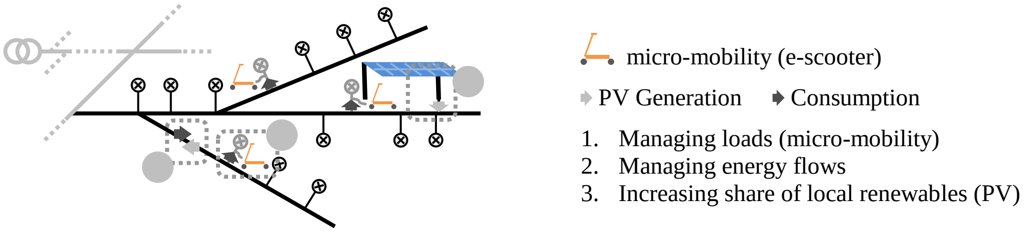
e) Optimized Split (OS)

Figure 2: a) IA: Loads are immediately accepted unless the acceptance is causing an overload. In the latter case, loads are finally refused (red). **b) TSW**: The new load causing an immediate overload is time shifted as a whole without interrupts until the demand can be met till the departure (green) or it is refused. **c) TSD**: All new (green) and remaining loads (yellow) are rearranged / shifted as a whole without interrupts similar to TSW. An interrupt of a running load may be introduced (blue). **d) TSS**: The new load causing an immediate overload is shifted also as segments with interrupts until the demand can be met till the departure (green) or it is refused. **e) OS**: The complete schedule is rearranged, split and shifted for all load with interrupts.

Our results showed an increased amount of acceptance of loads and increase of delivered energy for all strategies except for the complete dispatching of all loads. The decrease of the time resolution increased the delivered energy. The time based shift as a whole (TSW) showed less effect than the other strategies. The optimized splitting (OS) showed no improvements and failed in our simulation because of the large solution space with 15 minute time steps could not be solved with the chosen genetic algorithm. In a stab line network, the impact of the displacement to another access point is much higher than the offer of a decreased state of charge. The stab line network was limited because of the operation voltage and never because of the ampacity, whereas the random network was limited by the operation voltage and the ampacity as well. In conclusion, the impact of different load management strategies were analyzed and compared amongst each other.

Phase 3: implementation of smart poles in an energetic community with high penetration of renewable energy

As a future vision for the project, a proposed strategy to increase the share of locally generated renewable energy from distributed PV systems by implementing a smart load management system to support power applications, mainly electro-mobility, is presented in the third phase of this work (Figure 3).


micro-mobility (e-scooter)

PV Generation Consumption

1. Managing loads (micro-mobility)
2. Managing energy flows
3. Increasing share of local renewables (PV)

Figure 3: micro-mobility load management with smart poles

The underlying concept is to increase the utilization factor of the low voltage distribution networks by absorbing the locally generated renewable energy with controllable loads connected to charging points near the source of generation.

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