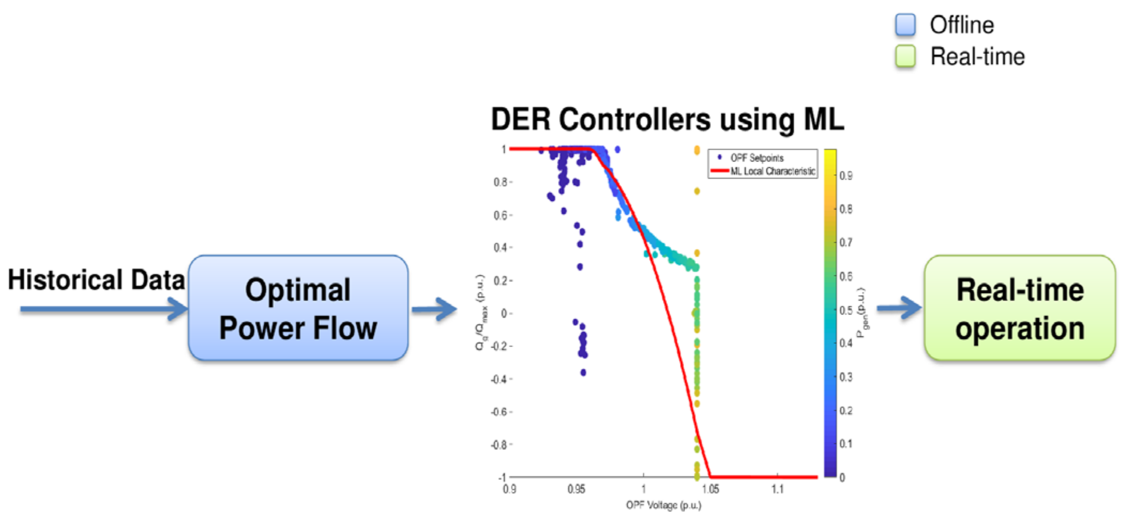
Optimized Local Control using Machine Learning

Overview

The increasing penetration of Bottom-up-Technologies in low voltage networks is posing new challenges to Distribution System Operators (DSOs) in terms of grid stability, energy balance and grid utilization. The considered decentralized control scheme, developed at the Power Systems Laboratory (ETH-PSL) proposes solutions to these challenges, by implementing innovative approaches that combine advancements in computational procedures, and the modern technological progress, e.g. faster response-time of electronic power inverters. The use of Machine Learning leads to building more accurate local controllers to tackle system-wide problems. The proposed approach is implemented at Empa on parts of the NEST demonstrator to verify benefits in terms of operating and investment costs and voltage stability. Next to the grid connected operation of the control scheme, it can be extended for islanded operation mode leading to exploiting further investigations in the area of optimal energy management for microgrids. More specifically, the self-consumption of microgrids can be maximized by identifying the optimal battery behavior through forecasting processes. The voltage stability is at the same time guaranteed by applying the proposed local control to the DER grid inverters.

Optimized Local Control Scheme



DER Local Controllers Design

The proposed optimized scheme controls locally each Distributed Energy Resource (DER) of a distribution grid without the need of prone and costly communication and monitoring infrastructure. It solves the problems of power quality and power balance by exploiting the flexibility provided by Bottom-up-Technologies and thus defers conventional network reinforcements. Multiple aspects for Distributed Energy Resources (DERs) are considered: Active Power Curtailment (APC), Reactive Power Control (RPC), Battery Energy Storage Systems (BESSs) and Controllable Loads (CLs), or combination of these.

The proposed approach is able to utilize the flexibility offered by DERs. System-wide challenges are addressed by using purely local controllers, thus increasing grid performance at no extra investment or operational cost.

The main goal is to directly control the targeted grid by defining explicit and real-time setpoints for power absorption/injection for DER inverters. The following steps are implemented:

- A centralized, Optimal Power Flow-based, operation scheme is derived form historical data to generate a sequence of optimal DER setpoints at different operating conditions, considering the availability of several active control measures;
- Machine Learning (ML) techniques are applied to the generated dataset in order to develop local characteristic curves that provide the optimal active/reactive power injection/consumption for each value of the local voltage magnitude;
- The local DER controllers are applied in real-time operation achieving near-optimal solutions without the use of communication infrastructure between the different units.

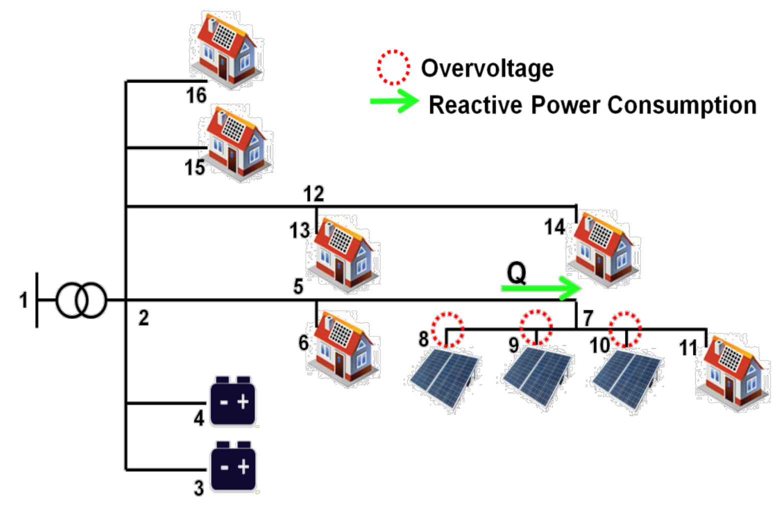
Implementation at NEST

The NEST electrical grid model, i.e. buses, lines, cables specifications, has been designed and validated on historical data comparing the simulated behavior against the real one. The battery is forced to work in a high-injection regime during noon hours, always respecting its operating limits to simulate a solar panel and create an over voltage situation. Thus, more overvoltage issues are forced and additionally their intensity is increased by 1-2V. All other systems, including heat pumps, behave as additional uncontrollable loads. Finally, local characteristic curves are designed for PV inverters and integrated in the real-time operation using a LabView interface with no hardware adjustments.

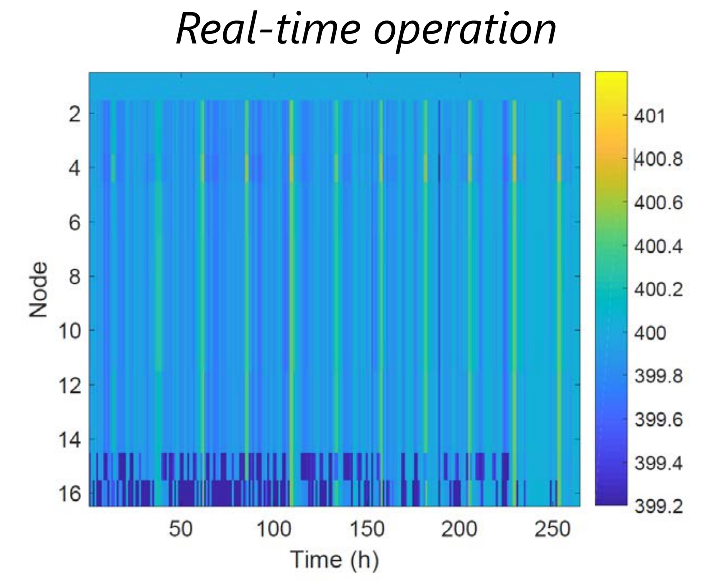
The application of the considered optimized local control scheme to NEST has the objective to test the efficiency of the proposed solution in terms of grid stability against other existing decentralized control methods, e.g. German standard local control according to VDE.

Setting the maximum acceptable local voltage at 400.4V in the offline centralized Optimal Power Flow, it results that the proposed control scheme reduces the voltage magnitude deviations by 0.5V against the 0.1V gain obtained implementing the existing VDE control.

Active and reactive power injected by non controllable-loads influences the voltage magnitude in the distribution grid. The implemented control algorithm considers this, which results in a compensation of reactive power.



Real-time operation



The NEST voltage magnitudes

Relevance to Industry

DSOs are going to face new challenges due to the increasing amount of renewable flexible prosumers. These behave less predictable as they control their flexible components e.g. heat pumps, batteries, solar panels and super-capacitors according to their own, individual objectives. These are arbitrary from the perspective of a DSO and thus the variability of power injections increases. The bi-directionality of the power flow can causes voltage and thermal-overload issues traditionally solved by investing in network expansion. Nowadays the integration of the operational flexibility in the planning stage upgrades the passive role of Distribution Networks and allows to find cost-effective solutions and increasing the system security. The focus lies on utilizing the extensive infrastructure by actively controlling individual existing DER with the objective of optimizing grid safety operation in both grid-connected and islanded operation mode.

By unlocking the full potential of the new smart-grid technologies, the proposed optimized local control scheme achieves near optimal solutions to system-wide problems, offering the chance to integrate new innovations in the electricity networks without investing in grid expansion strategies.

PSL Power Systems Laboratory

ehub | Empa

Ralf Knechtle
ralf.knechtle@empa.ch

Federica Bellizio
bellizif@student.ethz.ch