Analysing the effect of switch positions on power grid stability and development of optimal switch state optimizer

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Abstract

In modern distribution grids electricity is both produced and consumed on a local level. Unlike in the past when energy usually flowed from the transformer to the consumers, nowadays, electricity may be produced and consumed within the same grid. This leads to complex powerflow within the distribution grids. Venios simulates these grids (in real time) using measurement data, prediction algorithms and whether forecasts. Using this "digital twin" of the grid computational studies for improvements of the grid can be performed. Improvements desirable for the grid operator might aim at getting a lower overall utilization, higher grid stability, lower operating costs or lower expansion costs among others[1]. The aim of this project is to explore the effects of connecting or disconnecting different sub islands of the grids with each other/from each other. Once these effects are established am algorithm finding the **optimal switch states** can be developed.

Model: the grid

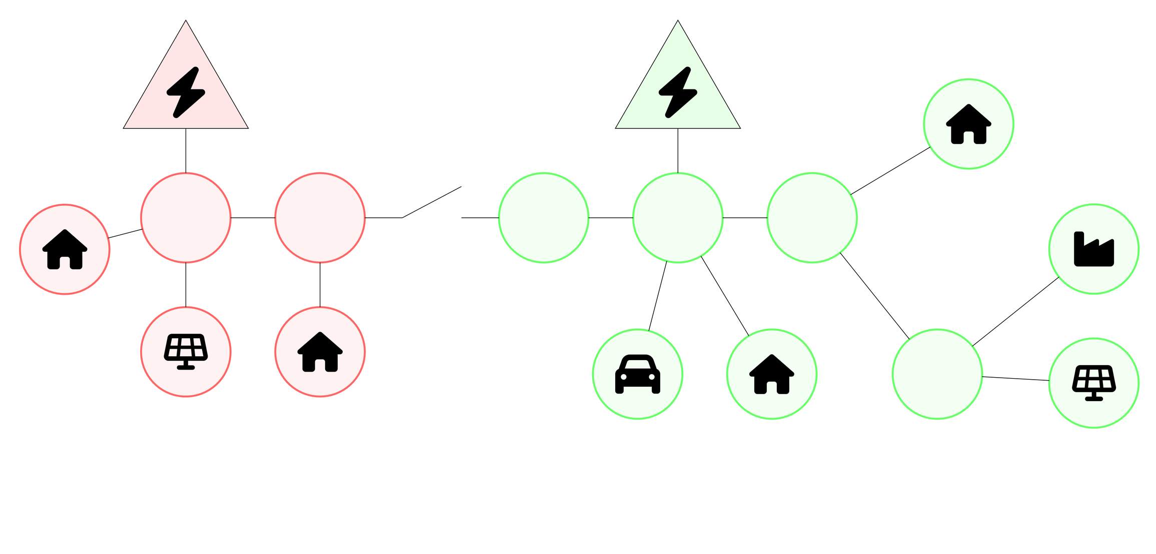


Figure 1. Two electricity grids that are connectable through a switch

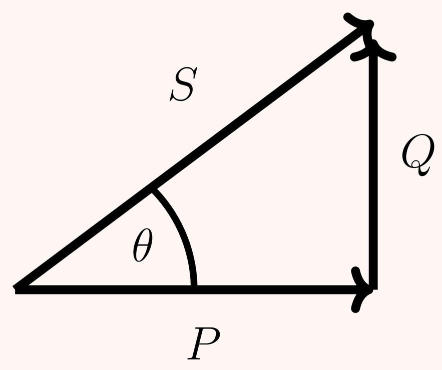
A typical distribution grid has many types of prosumers connected like households, industries, solar panels, electric car charges and others. Usually all electricity has to come or go to the medium voltage grid through the transformer. However, if the grids are connected electricity can flow directly between produces and consumers.

AC Equations

$$\begin{aligned} \text{Voltage:}\quad & V(t) = V_m \cos(\omega t + \theta_V) \\ \text{Current:}\quad & I(t) = I_m \cos(\omega t + \theta_I) \\ \text{Power:}\quad & P_r(t) = V(t) I(t) \end{aligned} \tag{1}$$

Where V_m and V_m are the magnitudes of voltage and current respectively, ω the angular velocity of the oscillations and θ_V and θ_I the phase offset of Voltage and current respectively.

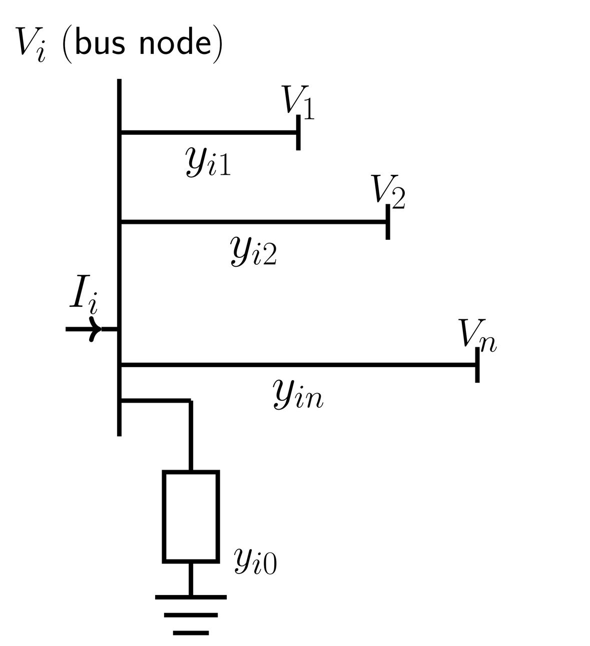
Model: complex valued formulation



$$\begin{aligned} \text{Complex power:}\quad & S = P + iQ \\ \text{Apparent power:}\quad & |S| = |V||I| = V_m I_m \\ \text{Impedance Angle:}\quad & \theta = \theta_V - \theta_I \\ \text{Active (real part):}\quad & P = |V||I| \cos\theta = V_m I_m \cos\theta \\ \text{Reactive (imaginary part):}\quad & Q = |V||I| \sin\theta = V_m I_m \sin\theta \\ \text{Power factor:}\quad & P_f = \cos\theta \end{aligned} \tag{2}$$

Model: powerflow

Solving power flow means figuring out the voltage at each node and the current flowing into it.



$$\begin{aligned} \text{Reistance :}\quad & R \\ \text{Reactance :}\quad & X \\ \text{Impedance :}\quad & Z = R + iX \\ \text{Admittance :}\quad & Y = 1/Z = \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & \cdots & & \\ \cdots & & \cdots & \\ y_{n1} & & & y_{nn} \end{pmatrix} \\ \text{Ohm's law :}\quad & V = ZI \\ \text{Powerflow :}\quad & I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j = \frac{S_i^*}{V_i^*} \quad i \neq j \end{aligned} \tag{3}$$

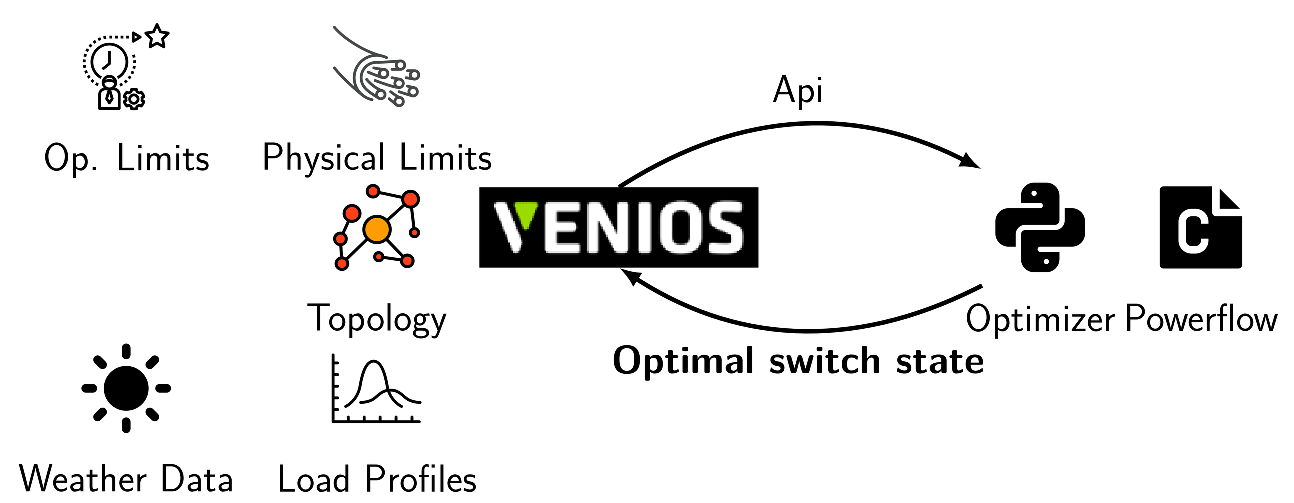
Figure 2. Schematic of a powerflow node[2]

Equatiom, as V_i appears on both sides it is non-linear and can only be solved computationally

To solve power flow each node in the grid is modelled as one of two types:

Name	Known	Example	Number
Slack	V	Transformer or big prosumer	One
PQ	P & Q	Any prosumer	Any

Method: interacting with VEP



Method: solving powerflow

- **Gauss Seidel**: Easy to implement, but slow and bad convergence
- **Newton Raphson**: More complex, but very fast

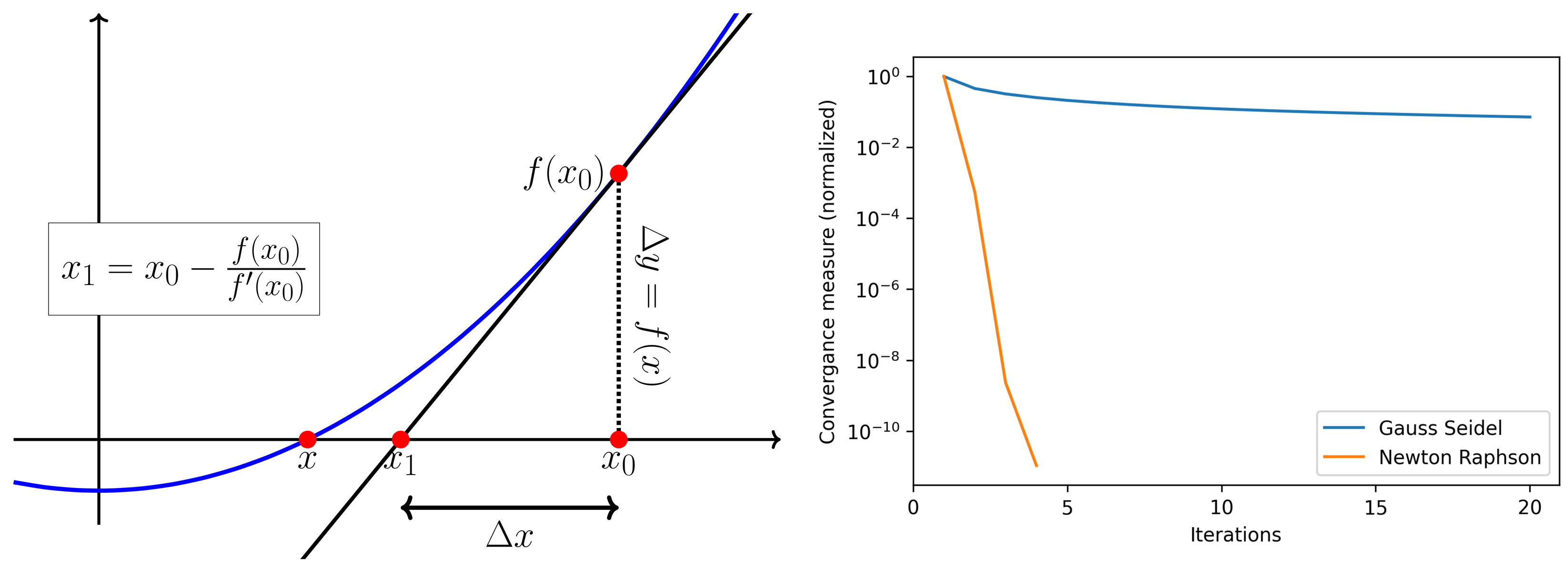


Figure 3. Illustration of Newton Raphson method (left); Convergence speed of two tested power flow solvers in log scale (right)

Powerflow result

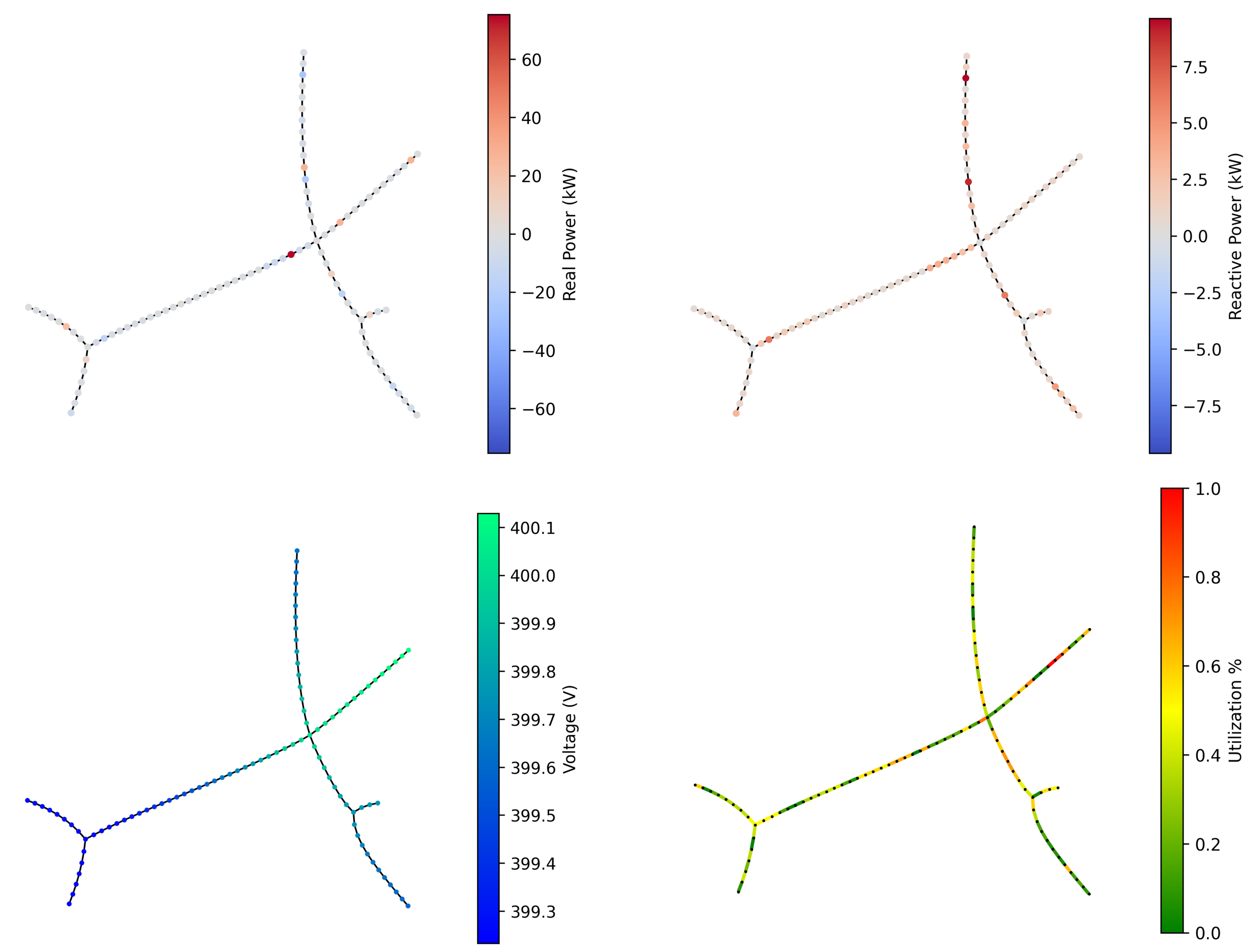


Figure 4. Results of powerflow simulation of a life-like synthetic German grid[3] using Newton Raphson. Real Power P (eq. 2) of each node (top left); Reactive Power Q (eq. 2) of each node (top right); Node voltage (eq. 2) (bottom left); Node voltage (eq. 2) (bottom left); Cable utilization factor $\frac{I_{max}}{I}$ (bottom right)

Typical German urban grid

Switch states $= 2^{\text{Number switches}}$

- $100 - 1000$ Prosumers per grid[1]
- $1 - 4$ connections to neighbouring grids[1]
- City of 500.000 people tends to have 1000 grids[1]
- High percentage of households/industries generating power

Challanges and Solutions

To find **optimal** (or even improved) **switch states**, two challenges emerge: what does *improved* mean and which configurations should be considered?

Measures to assess grid quality:

- Overall line losses
- Utilization of cables
- Utilization of transformers
- Number of transformers
- Voltage stability
- Expandability robustness

Switching Strategies:

- Quantify how different two configurations are and pick very different ones
- Use centrality measures
- Balance the number of nodes or the load sum of nodes connected to one transformer
- Bad apple
- Random
- Determine typical grid topologies

References

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2. Saadat H. Power System Analysis. Ed. by Coman MK. 2nd ed. McGraw-Hill Higher Education, 2002
3. Meinecke S, Sarajlić D, Drauz SR, Klettke A, Lauven LP, Rehtanz C, Moser A, and Braun M. SimBench—A Benchmark Dataset of Electric Power Systems to Compare Innovative Solutions Based on Power Flow Analysis. Energies 2020; 13. DOI: 10.3390/en13123290. Available from: https://www.mdpi.com/1996-1073/13/12/3290