DETERMINATION OF OPTIMAL FLEXIBILITY POTENTIAL FOR AN ELECTRICAL DISTRIBUTION NETWORK

Rajkumar PALANIAPPAN[1], Muhammad Sohaib IRSHAD[1], Christian REHTANZ[1]

Introduction

The introduction of renewable energy sources (RES) into the MV and LV grids is converting the passive grids to active grids with bidirectional power flows. Such bidirectional power flows introduce complications such as voltage limit violations, line overloading, transformer overloading and power quality problems. In order to solve the problems associated to the increased share of RESs, there are certain actions that the distribution system operators could take.

The first possibility is to improve the overall network information situation by installing more measurement devices. The second option is to introduce smart network control through actuators for controlling the transformer taps and active power fed into the system to compensate primarily for the small voltage problems associated with active power peaks. The third option is the withdrawal and feed in of the active power (P) in conjunction with the reactive power (Q) dispatch which is system oriented. In the case of limit violations, control commands for the available actuators are then derived using state of the art optimization algorithm as defined in this paper.

To be able react quickly and cost-efficiently to the changing technical and regulatory requirements, a flexible function adaption based on reusable hardware and software systems is required. In the research project i-Automate [1], partners from universities and industry develop such a portable, modular and flexible system architecture. In the project i-Automate, measurements are acquired from different points of the distribution grid that are then processed in a State Estimation algorithm to identify the overall system state. It is then used in a voltage regulation algorithm [2] for solving the voltage violations.

This paper deals with the implementation of an optimal power flow (OPF) algorithm that could potentially replace the existing voltage regulation algorithm. As an initial step, the OPF algorithm is implemented in Pandapower to investigate the possibilities and challenges of the algorithm to be later implemented in the hardware device. The medium voltage (MV) network elements modelling employs Python as a primary programming language and Pandapower (Python) as a primary open source software framework for power flow analysis. An optimization algorithm (Python Interior Point Solver) is employed which would satisfy the constraints and gives the best possible and most economical set points for remotely controllable actuators which include controllable inverters attached to RESs feeding the P and Q into the system and energy storage systems as well as OLTC.

Optimal Power Flow algorithm

The OPF method described in this paper helps determine the state of the power system, which translates to cost effective and reliable operation of the system. The operational and physical constraints most commonly includes line loadings (current), transformer loadings, voltage constraints, minimum and maximum output capability of generators and maximum number of transformer stepping. The OPF objective function that translates to cost minimization while satisfying the constraints is shown below:

$$Min\ F_g = \sum_{i=1}^{n} \left(a_i {P_{gi}}^2 + b_i P_{gi} + c_i + d_i {Q_{gi}}^2 + e_i Q_{gi} + f_i\right) + \Delta\,(t)^2$$

$$P_i^G - P_i^L = \sum_{j=1}^{N} V_i\, V_j\ [G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j) \qquad i = 1\ to\ N$$

$$Q_i^G - Q_i^L = \sum_{j=1}^{N} V_i\, V_j\ [G_{ij} \sin(\theta_i - \theta_j) + B_{ij} \cos(\theta_i - \theta_j) \qquad i = 1\ to\ N$$

[1] Institut ie3, TU Dortmund University, Emil-Figge-Str. 70, 44227 Dortmund, Tel:+49-231-755-2395, Fax: -2694, www.ie3.tu-dortmund.de

$$V_{min,j} \leq V_j \leq V_{max,j} \qquad j\epsilon bus$$

$$\frac{V_i^2 + V_j^2 - 2\,V_i\,V_j\,\cos(\theta_i - \theta_j)}{Z_L(l)^2} - I_{L,max}^2(l) \leq 0 \qquad l = 0,1,2 \ldots .Nl$$

$$P_{min,gi} \leq P_{gi} \leq P_{max,gi} \qquad g\epsilon generator$$

$$Q_{min,gi} \leq Q_{gi} \leq Q_{max,gi} \qquad g\epsilon generator$$

$$P_{min,eg} \leq P_{eg} \leq P_{max,eg} \quad eg\epsilon \text{ external grid}$$

$$V_{min,j} \leq V_j \leq V_{max,j} \qquad j\epsilon bus$$

The combination of the different available flexibilities are used for the optimization. The Q flexibility for each RES is estimated by optimizing the Q output for each RES. If the algorithm converges, then the Q flexibility in the MV grid can be used to solve for violations in the network. In case of non-convergence, P and Q flexibility for each RES is optimized by adding the P contribution of each RES in addition to Q flexibility into the cost function. In case of non-convergence again, discrete transformer stepping are included as an additional flexibility. Non-convergence from the last step theoretically means no optimization solution is available and the available flexibilities are insufficient. In this case, battery storage systems are added as an additional flexibility in the system to further enhance the potential.

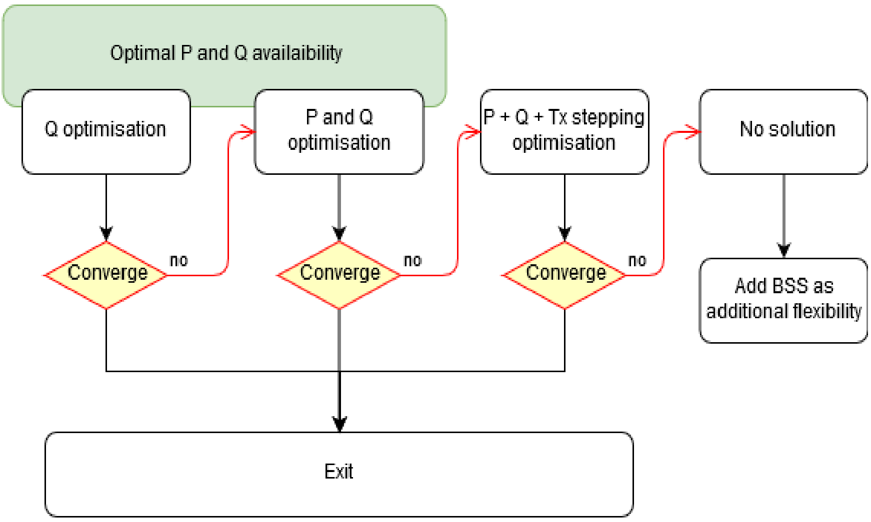

Figure 1: Stepwise implementation of OPF

Conclusion and Outlook

In this work, an OPF algorithm was implemented and validated that could replace the existing voltage regulation algorithm available in the i-Automate devices. The advantage is that all the combination possibilities of the flexibilities are available to avoid limit value violations. Thus, the best possible solution could be found that is ideal in terms of the cost function that can be parameterized by the user, or at least close to the best solution. It should be noted that this is only the first step and the OPF algorithm should be further implemented in the hardware devices to be validated in a laboratory setup with a real-time simulator and later in the field using real world measurements.

References

[1] B. Bauernschmitt, R. Palaniappan, D. Hilbrich, C. Rehtanz: Modular Configurable and Testable Automation Architecture for future Active Electrical Energy Grids, 53rd International Universities Power Engineering Conference, Glasgow, Scotland, September 2018

[2] R. Palaniappan, B. Bauernschmitt, D. Hilbrich, C. Rehtanz: Co-ordinated voltage regulation using distributed measurement acquisition devices with a real-time model of the Cigré low-voltage benchmark grid, IET Generation, Transmission and Distribution, Volume 13, Issue 5, 12 March 2019, p. 710 – 716, DOI: http://dx.doi.org/10.1049/iet-gtd.2018.5300