Mixed-integer non-linear programming approach for identifying parameters inconsistencies in load flow calculations

Pierre Arvy

Artelys France

pierre.arvy@artelys.com

Keywords : *mixed-integer non-linear programming, non-linear optimization, divergence analysis, load flow calculations.*

Abstract

For several decades, electrical networks have experienced continuous expansion in size and scale, facilitating the transmission of electrical power from sources to end-users. The growing complexity of these networks necessitates the use of tools like Load Flow (LF) calculations, which are crucial for power systems engineering, playing a critical role in ensuring grid reliability and efficiency [1]. This numerical analysis of electric power within interconnected systems determines steady-state voltages, currents, and power flows across network components [4].

Given the significance of LF calculations, the power systems community has invested substantial efforts in enhancing the convergence of the methods used to solve them [6], including the associated optimization problem known as Optimal Power Flow [2, 3]. Despite these efforts, real-world scenarios, especially in power system planning, often involve imperfect or erroneous network parameters, leading to challenging convergence issues for existing methods [5]. The physical problem studied may be mathematically infeasible due to complex inconsistencies in the parameters, yet the divergence of applied methods is not a clear certificate of this. Consequently, power system engineers usually engage in iterative processes to pinpoint the moment at which divergences occur and identify the responsible parameters, making it a time-consuming endeavor.

This research project explores a novel approach centered around Mixed-Integer Non-Linear Programming (MINLP) to detect inconsistencies or errors in the parameters of a power network, on which LF calculations are applied and divergent. The MINLP is obtained by utilizing the non-linear LF equations as constraints and transforming the various network parameters involved in these equations into penalized variables. This transformation facilitates parameters adjustments -or corrections- while the MINLP minimizes them, using binary variables as activators of these modifications. This introduces additional variables and constraints into the optimization problem, following a conventional form in operations research. Solving the MINLP identifies thus the inconsistencies in the power network's parameters, corresponding to the adjusted values.

The study extends with the implementation of an open-source tool[1], integrated with the openly shared PowSyBl Java framework[2], widely used in the power systems community for LF analyses. It relies on an implementation of the previously discussed MINLP using the AMPL modeling language, and conducts a solution to this non-linear and non-convex optimization

[1]Available at the following link: https://github.com/powsybl/powsybl-optimizer/tree/divergence-analyser

[2]Obtainable via the following link: https://github.com/powsybl

problem using the commercial solver Artelys Knitro. Interior-point algorithms are employed for solving the non-linear relaxation of the problem, along with the non-linear branch-and-bound algorithm of the solver for handling the non-continuous problem.

Finally, the research project outlines the validation procedure of the implemented tool. Validation through the detection of inconsistencies in power network parameters is based on unit tests manually generated from both open-source and real-world use cases. Besides, the tool successfully identifies inconsistencies in an operational scenario involving a real-world case with parameter inconsistencies. The average computation time of the tool is also analyzed, demonstrating its practical usability by power systems operators. Furthermore, based on observations and results obtained, the study presents future research directions to enhance the detection of parameter inconsistencies in power networks. These directions include using other formulations of the objective function of the presented MINLP, exploring alternative load flow formulations, and integrating validated physical inequalities as constraints.

References

[1] Olukayode Afolabi, Warsame Ali, P. Cofie, John Fuller, Pamela Obiomon, and Emmanuel Kolawole. Analysis of the load flow problem in power system planning studies. *Energy and Power Engineering*, 07:509–523, 01 2015. doi:10.4236/epe.2015.710048.

[2] Stephen M. Frank, Ingrida Steponavice and Steffen Rebennack. Optimal power flow: a bibliographic survey I. *Energy Systems 3 (2012)*: 221 - 258.

[3] Stephen M. Frank, Ingrida Steponavice and Steffen Rebennack. Optimal power flow: a bibliographic survey II. *Energy Systems 3 (2012)*: 221 - 258.

[4] John J. Grainger and William D. Stevenson. *Power system analysis*. New York: McGraw-Hill, 1994.

[5] Jigar Patel, Daivat Desai, Vaibhav Patel, Dishang D. Trivedi, and Santosh C. Vora. Analyzing effect of bad measurement data on load flow and state estimation in power system. *in 2015 5th Nirma University International Conference on Engineering (NUiCONE)*, pages 1–6, 2015. doi:10.1109/NUICONE.2015.7449618.

[6] Brian Stott. Review of load-flow calculation methods. *in Proceedings of the IEEE*, vol. 62, no. 7, pp. 916-929, July 1974, doi: 10.1109/PROC.1974.9544.