POWER FLOW CALCULATION METHODS: A COMPREHENSIVE REVIEW

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Motivation und zentrale Fragestellung / Motivation and Key Research Questions

The problem of power flow calculation is as old as it is fundamental to power system studies. It is perhaps the most fundamental tool in (electric) power system analysis, given its wide variety of applications. Due to its pervasiveness, a considerable number of research efforts have been made (and are still being made) in order to better understand the nature of the problem and to find or improve solution methods. The purpose of this paper is to provide a structured and *up-to-date* overview of existing solution methods to the power flow problem and gather quantitative results regarding their efficacy from the available literature.

Methodische Vorgehensweise / Methods

The introductory section of this work briefly outlines the history of the power flow problem and provides a (mostly chronological) summary of the development of solution methods. A number of applications of power flow calculation are mentioned for context.

Control schemes, such as advanced voltage control, Flexible AC Transmission System (FACTS) devices and reactive power limits of generators are *not* a subject of this paper. Note that the manner of their inclusion can drastically affect computation speed and convergence behavior of iterative methods.

The analysis is started off by a comprehensive formulation of the fundamental problem of power flow, outlining the scope of the problem to solve. Unifying and standardizing the different notations used in the examined previous works is the first contribution which this paper aims to provide. This forms the basis for a consistent and precise description of each solution algorithm in the second part of the analysis, detailing (step by step) how the basic problem formulation must be amended in order to apply a specific solution algorithm.

Major emphasis is put on the now de-facto industry standard Newton-Raphson algorithm [1] and several of its variations and modifications, including the (Fast) Decoupled Load Flow [2] and Newton-Raphson with constant matrices [4, 5]. Other examined methods include the Gauss-Seidel method (and other fixed-point Y-matrix based methods) and the more recently developed Holomorphic Embedding Load Flow (HELM) method [3].

Ergebnisse und Schlussfolgerungen / Results and Conclusion

It proves notoriously difficult to accurately and reliably compare results from different sources, given the simple fact that investigation scopes, frameworks, test cases and implementations can vary widely from one publication to the next.

Evaluation of power flow algorithms is done in most cases according to three major criteria: computational burden (speed and memory requirements), convergence behavior (for iterative methods) and solution accuracy. Consequently, the numerical results referred to or presented in this paper also fall into these categories.

Key observations from the examined literature include the following:

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- Investigations regarding computation speed and convergence behavior are often carried out for a very limited number of generation and load scenarios, even in research papers which aim to provide quantitatively reliable results.
- All iterative methods have an inherent risk of non-convergence even if there is a solution. Attempts to increase computational performance can impair convergence behavior [5].
- For different iterative methods, computation time scales differently with network size.
- On large networks (> 2000 buses), the Fast Decoupled Load Flow method [2] shows significant drawbacks in computation time of up to 3 orders of magnitude compared to the standard Newton-Raphson algorithm [4].
- The Holomorphic Embedding Load Flow method avoids problems of non-convergence. It becomes especially effective when it is used to provide a starting solution for some other iterative method [4].

Referenzen / Literature

[1] W. Tinney, C. Hart, “Power Flow Solution by Newton's Method” *IEEE Transactions on Power Apparatus and Systems*, 1967.

[2] B. Stott, O. Alsac, “Fast Decoupled Load Flow,” In *IEEE Transactions on Power Apparatus and Systems*, 1974.

[3] A. Trias, “The Holomorphic Embedding Load Flow method,” *2012 IEEE Power and Energy Society General Meeting*. San Diego, California, USA, 22-26 July 2012.

[4] Sauter, P. S.; Braun, C. A.; Kluwe, M.; Hohmann, S.: P. S. Sauter, C. A. Braun, M. Kluwe, S. Hohmann, “Comparison of the Holomorphic Embedding Load Flow Method with Established Power Flow Algorithms and a New Hybrid Approach,” *2017 Ninth Annual IEEE Green Technologies Conference (GreenTech)*. IEEE, 2017.

[5] S. Janković, B. Ivanović, “Application of combined Newton–Raphson method to large load flow models,” *Electric Power Systems Research*, 2015.