

ON LOAD FLOW METHODS AND DYNAMIC EQUIVALENTS  
FOR INTEGRATED POWER SYSTEMS

DLS

by



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This thesis is dedicated

to my wife

Meera

C E R T I F I C A T E

This is to certify that the thesis entitled, " ON LOAD FLOW METHODS AND DYNAMIC EQUIVALENTS FOR INTEGRATED POWER SYSTEMS " being submitted by Shri D.L. Shenoy for the award of the degree of Doctor of Philosophy, to the Indian Institute of Technology, Delhi, is a record of bonafide research work he has carried out under our guidance and supervision. The results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

This thesis addresses itself to the two important problems in power system analysis viz load flow study and dynamic equivalentencing for transient stability studies.

Load Flow Study:

Bus power computations are required to obtain the mismatch vector for every iteration in Newton-Raphson load flow methods. These computations during the iterative procedure are normally performed through the use of calculated bus currents and updated bus voltages involving considerable amount of computational time. An efficient formulation for bus power computations is proposed which simplifies these otherwise involved/cumbersome computations to a triviality of just four multiplications and four additions per bus. The formulation developed has been applied to first order NR methods in rectangular form employing constant Jacobian. The use of this formulation has also been made applicable to decoupled load flow methods with variables in rectangular coordinates.

It is analytically established that the second order load flow and first order NR load flow methods in rectangular form generate exactly the same iterates and all the computational advantages of the former are also available with the latter.

In one of the new Newton based load flow methods presented in this thesis reactive bus power equations in the usual formulation are replaced by equations pertaining to the imaginary

parts of bus current mismatches. Two versions of this hybrid method in rectangular form have been developed and investigated. These are - one with the Jacobian re-evaluated at the beginning of each iteration and the other with the initial Jacobian held constant throughout the iterative process. Investigations involving normal as well as ill-conditioned systems have been carried out and it is established that the use of hybrid defining functions of bus active powers and imaginary parts of bus current mismatches lead to algorithms which are computationally more efficient and have better reliability than the corresponding versions of usual Newton-Raphson methods in P-Q form.

It is recognised that the fast decoupled load flow (FDLF) method of Stott and Alsop [ 21] has the distinct advantages by way of reduced storage and computational speed. However, FDLF being a Newton based method with variables in polar coordinates, involves bus power computations requiring trigonometric functions evaluations which are time consuming. Combining the efficient procedure for bus power computations and the better features of hybrid load flow method developed in the thesis alongwith the well known features of the FDLF method, two decoupled constant matrix load flow methods in rectangular coordinates have been developed. The new decoupled load flow methods are -

- (1) decoupled second order load flow (SOLF) and
- (2) decoupled second order hybrid load flow (SOHLF).

Investigations involving several normal as well as ~~ill~~-conditioned

systems have been carried out using the proposed decoupled second order load flow and second order hybrid load flow methods and their performances are compared with the FDLF method. The limited investigations carried out reveal that both the proposed decoupled load flow methods are highly reliable and computationally more efficient than the FDLF method. The memory requirements of the decoupled SOLF and SOHLF methods are of the same order as the FDLF method.

#### Dynamic Equivalents for Transient Stability Studies.

1. Stability investigation of power systems is one of the most fundamental and important study necessary for system planning, design operation and control.
2. Owing to the order of interconnected power system, it is often, uneconomical and impractical to represent the entire system in detail for transient stability studies.
3. Under such circumstances, it is therefore, frequently expedient to restrict the use of detailed mathematical description for each component model to that subsystem whose detailed dynamics are under study. The rest of the system (external subsystem) where the internal performance is not of particular significance, is then represented appropriately by simple dynamic equivalents so as to adequately capture the influence of the rest of the system on the performance of the study subsystem.

In this work two types of dynamic equivalents for transient stability studies have been proposed. One of these methods uses a set of new distribution factors based on a moment concept. The equivalent is constructed by computing distribution factors for all generator buses and load buses in the external subsystem. The distribution factors so obtained are used to assign all the dynamical quantities as well as the generations for the equivalent generators at the boundary buses of the study subsystem. Transient stability analysis for two existing Indian Power Systems pertaining to two States, one consisting of 28 buses, 9 generators, 45 lines and the other consisting of 96 buses, 20 generators, 137 lines have been carried out using the distribution factors based on the moment concept and the distribution factors of Brown et al [69] in order to bring forth some critical comparison between the two approaches. The stability equivalent based on the moment concept provides sufficiently close results for faults at locations which are not too close to the boundary buses of the study-subsystem. However, it may not always provide accurate enough results for disturbances at or very close to the boundary buses of the study subsystem comparable to those obtained with the actual full unreduced system simulation. In view of this, yet another new approach using the concept of distribution factors has been developed. In this approach, each generator in the external subsystem is first represented by several component

generators equal to the number of the study-subsystem. The inertia constants, transient reactances and generations of these generators are assigned in accordance with the appropriate distribution factors. Component generators corresponding to like distribution factors are then shorted together to form a set of newly formed buses outside the external networks. The main highlight of the approach is that the external subsystem is kept intact along with the loads and is then reduced to obtain network mesh consisting of the boundary buses study subsystem and an equal number of newly formed buses. Tests on the two real life Indian power systems (as detailed earlier) indicate that the stability equivalent thus obtained provides accurate enough results for transient stability studies.

The main contributions of the thesis are summarised below:

- (1) An efficient procedure for extreme simplification of the otherwise cumbersome repetitive bus power computations in the first order constant matrix Newton based methods with variables in rectangular form has been developed. The application of the efficient procedure has also been extended to methods employing variable Jacobian and to second order and decoupled load flow methods.
- (2) A conclusive proof is advanced establishing that the second order load flow and first order constant Jacobian NR methods in rectangular form generate exactly the same iterates.

- (3) A NR load flow method with defining functions of bus active powers and imaginary parts of bus injected currents leading to a superior load flow algorithm as compared to the usual NR load flow method has been formulated.
- (4) Two highly reliable decoupled load flow methods with variables in rectangular form have been developed which are computationally more efficient than any of the existing decoupled load flow methods and the FDLF method.
- (5) New and effective dynamic equivalents based on a moment concept have been proposed for carrying out fast and yet accurate transient stability analysis for large integrated power systems.

The utility and potential of various methods/algorithms developed in this thesis have been fully demonstrated through several test systems which also include two real life Indian power systems.

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