Electric Power Systems Research 80 (2010) 1385–1393

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Review

# Review of reduction techniques in the determination of composite system adequacy equivalents

A. Akhavein[a], M. Fotuhi Firuzabad[b,*], R. Billinton[c], D. Farokhzad[d]

[a] Department of Engineering, Islamic Azad University, Science & Research Branch, Tehran, Iran
[b] Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
[c] Department of Electrical and Computer Engineering, University of Saskatchewan, Saskatoon, Canada
[d] Iran Grid Management Company, Tehran, Iran

ARTICLE INFO

*Article history:*
Received 17 January 2010
Received in revised form 27 May 2010
Accepted 4 June 2010
Available online 7 July 2010

*Keywords:*
Reliability equivalent
Adequacy equivalent
External network modeling
Network reduction

ABSTRACT

Reliability evaluation of a large composite power system involves the consideration of numerous outage events and consequently extensive calculations. Therefore, applying justifiable simplifications such as the determination of an equivalent networks can be very useful in reliability evaluation of large systems. This paper presents a review of procedures which are directly or indirectly applicable to the determination of composite system adequacy equivalents. Following a brief discussion on the basic characteristics of the various methods, their limitations are presented. Concluding points regarding the methods and modeling schemes related to adequacy equivalent are presented at the end of the paper.


**Contents**



* Corresponding author. Tel.: +98 21 66165901/21; fax: +98 21 66023261.
*E-mail address:* fotuhi@sharif.edu (M.F. Firuzabad).

0378-7796/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2010.06.002

## 1. Introduction

There are many instances in which studies are of more concern in one area of a power system and are not of direct concern in the remaining parts. The phrases "study area" (SA) and "external area" (EA) are used in this paper to describe the area in question and the remaining regions, respectively. Fig. 1 shows the partitioning of a power system into SA and EA. Boundary buses and tie lines can be defined in each SA or EA. It is usually intended to perform detailed studies in the SA. However, the EA is important to the extent where it affects SA analyses. The attraction to apply an equivalent for the EA increases as the dimensions of the power system and the complexity of the required analysis increases. This equivalent network reduces the dimensions of the EA and subsequently leads to reduction in the required time for analysis.

Reliability evaluation in a composite generation and transmission system is a problem with massive and time-consuming calculations and hence, it is an obvious candidate for the application of equivalent networks. Reliability analysis is conventionally categorized into adequacy and security problems. Adequacy is interpreted as the existence of sufficient facilities to supply the system loads with consideration of equipment constraints under static conditions. Security is a measure of system capability to withstand dynamic or transient disturbances [1].

The problem of finding a reliability equivalent (often adequacy equivalent) was first addressed by researchers in the 1970s. In this problem, it is intended to find an equivalent (simplified) model for an EA which facilitates adequacy evaluation studies. As the EA is usually the larger portion of the system, the connection of an EA adequacy equivalent to the SA reduces the calculation burden and makes the detailed reliability evaluation in the SA become more feasible.

This paper presents a review of methods, which are directly or indirectly related to the determination of adequacy equivalents. These methods can generally be divided into two types. The first type deals with finding an equivalent network for a portion of a system. Simplification of the reliability evaluation is the main focus in the second type.

Continuous enhancement in computer capabilities cannot generally obviate the need for adequacy equivalents in composite system reliability evaluation. This is because of concurrent increases in the sizes of interconnected power systems and in the complexity of their operation procedures. Power transfer agreements between power systems, deregulation and system restructuring and open access to transmission networks are such examples. In addition, limitations and costs of technical PC-based software usually limit the size of a system under study to a few hundred buses. It is therefore useful for a user to apply adequacy equivalents for the purpose of system size reduction.

Since a significant common concept exists between reliability and risk, these terms have been used interchangeably with the same meaning in this paper.

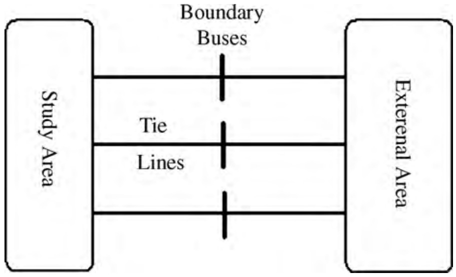


**Fig. 1.** Partitioning a power system into external and study areas.

## 2. Equivalent networks in load-flow studies

The issue of determining static equivalents for EA in load-flow studies dates back over 60 years. The use of equivalent networks proved to be successful and equivalent network concepts have been extended in other fields such as security and steady-state stability analysis.

An equivalent network is generally obtained for an operating point (called the base condition) in the power system. It is often assumed that in the base condition, loads are at peak values, circuit breakers are in their normal state and no element outages exist [2–5]. Some papers utilize the average load condition [3,4]. Multiple base conditions corresponding to different loading levels have also been utilized [6]. It should be pointed out that equivalent networks are only exact at the base condition and greater deviation from this condition, leads to less precision [2,7,8].

### 2.1. Ward equivalent

Determination of a Ward equivalent for an EA contains three main stages [2,7,9–11]. In the first stage, with consideration of the base condition, power injections in the EA buses are converted into current injections. Gaussian reduction is used to omit EA buses in the second stage where the outcomes are equivalent current injections and fictitious admittances in the boundary buses between the EA and the SA. In the third stage, equivalent current injections are converted to corresponding equivalent power injections in the base condition. Fig. 2 shows an example of the Ward equivalent network of an EA in the boundary buses of a SA.

The older version of the Ward equivalent model is the admittance version in which power injections are converted to admittances in the base condition. This version has lower precision especially for PV buses [7,9–12].

### 2.2. Radial, equivalent and independent (REI) network

In a REI network, some or all of the power injections at the EA buses are substituted by one equivalent power injection toward the boundary buses. At least one equivalent generation node and one equivalent load node are usually assigned for generators and loads, respectively. Fig. 3 shows a typical REI conversion process in which *m* generators are transformed to a single equivalent REI generation node.

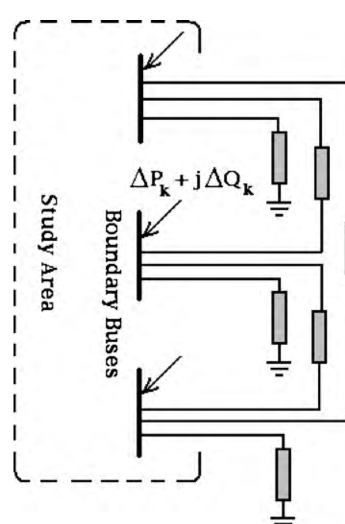


**Fig. 2.** Ward equivalent network of an external area with equivalent power injections in the boundary buses.