Available online at www.sciencedirect.com

ScienceDirect

Reliability Engineering and System Safety 93 (2008) 1473–1484

RELIABILITY ENGINEERING & SYSTEM SAFETY

www.elsevier.com/locate/ress

Reliability evaluation of deregulated electric power systems for planning applications

A. Ehsani[a,*], A.M. Ranjbar[a], A. Jafari[b], M. Fotuhi-Firuzabad[a]

[a]*Electrical Engineering Department, Sharif University of Technology, PO Box 11365-8639, Tehran, Iran*
[b]*Niroo Research Institute, PO Box 14665/517, Tehran, Iran*

Received 17 September 2006; received in revised form 21 September 2007; accepted 13 October 2007
Available online 26 October 2007

Abstract

In a deregulated electric power utility industry in which a competitive electricity market can influence system reliability, market risks cannot be ignored. This paper (1) proposes an analytical probabilistic model for reliability evaluation of competitive electricity markets and (2) develops a methodology for incorporating the market reliability problem into HLII reliability studies. A Markov state space diagram is employed to evaluate the market reliability. Since the market is a continuously operated system, the concept of absorbing states is applied to it in order to evaluate the reliability. The market states are identified by using market performance indices and the transition rates are calculated by using historical data. The key point in the proposed method is the concept that the reliability level of a restructured electric power system can be calculated using the availability of the composite power system (HLII) and the reliability of the electricity market. Two case studies are carried out over Roy Billinton Test System (RBTS) to illustrate interesting features of the proposed methodology.

Keywords: Deregulation; Electricity market; Markov modeling; RBTS; Reliability; Risk; Performance indices

1. Introduction

The electricity supply industry was in the hands of vertically integrated monopoly utilities for about a hundred years. Electricity market restructuring has been underway for more than a decade since the United Kingdom opened a Power Pool in April 1990. Restructuring has resulted in greater competition, greater emphasis on efficiency and reliability, and the development of a market structure for trading and supplying electrical energy [1].

The thrust towards privatization and deregulation of the electric utility industry has introduced a wide range of reliability issues that will require new criteria and analytical tools that recognize the residual uncertainties in the new environment. Traditional uncertainties associated with equipment availabilities will be augmented by a new set of concerns such as uncertainties associated with a competitive market mechanism [2–5].

There are many variations on the definition of reliability, but a widely accepted form [6] is: *Reliability is the probability of a device/component/system performing its purpose adequately for the period of time intended under the operating conditions encountered.* The criterion of ''adequate performance'' is an engineering and managerial problem. It is evident that the criteria of adequate performance for a restructured power system are not the same as the criteria for a traditional one (Fig. 1).

There is a wide range of probabilistic tools and indices, which can be used to effectively analyze the bulk system reliability. Traditionally, the basic techniques for reliability evaluation have been categorized in terms of their application to the main functional zones of an electric power system. These are generation systems, composite generation and transmission (or bulk power) systems, and distribution systems. The concept of hierarchical levels (HL) has been developed in order to establish a consistent means of identifying and grouping these functional zones.

*Corresponding author. Mobile: +98 912 3032916.
E-mail address: aehsani80@yahoo.com (A. Ehsani).

0951-8320/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2007.10.005

Nomenclature

i	index for generating unit
t	index for time
λ	failure rate (failures per year)
λ_p	permanent failure rate (failures per year)
MTTF	mean time to failure
$Pr_{Up}(t)$	probability of Up state as a function of time
ORR	outage replacement rate
$P_{i,min}$	minimum output power of the ith generating unit
ρ_{it}	energy price bid of the ith generator at time t
P_{it}	power of the ith generator at time t
N_G	total number of generators
$P_{Loss,t}$	power losses of transmission system at time t
$[B']$	constant square matrix in DC power flow formula
P_{lt}	power flow of the lth transmission line at time t
R_{it}	spinning reserve of the ith generator at time t
Dur	repair time
u_{it}	discrete variable that represents the status of the ith generator at time t and equals 1 if the unit is on and 0 if the unit is off
N_{Line}	total number of transmission lines
j	index for consumer (load)
l	index for transmission line
μ	repair rate (repairs per year)
λ_t	temporary failure rate (failures per year)
MTTR	mean time to repair
$Pr_{Down}(t)$	probability of Down state as a function of time
FOR	forced outage rate
$P_{i,max}$	maximum output power (capacity) of the ith generating unit
ρ_{itr}	reserve price bid of the ith generator at time t
P_{jt}	demand power of the jth consumer (Disco) at time t
N_D	total number of consumers (Discos)
$[B], B_0, B_{00}$	constants in the B matrix loss formula
$[\Delta\Theta_t]$	vector of system bus angles at time t
$P_{Limit,l}$	maximum transmission capacity of the lth line
RR_i	ramp rate of the ith generator in MW per minute
MCP_t	market-clearing price at time t
u_{itr}	discrete variable, which is 1 if the ith generator is committed for reserve at time t and 0 if it is not

These are illustrated (Fig. 2), in which the first level (HLI) refers to generation facilities, the second level (HLII) refers to the composite generation and transmission (bulk power) system, and the third level (HLIII) refers to the complete system, including distribution [7]. The target of this study is reliability evaluation of HLII in a competitive market environment.

We present a new method for evaluating reliability indices of a competitive electric power system. The key point in the proposed method is the concept that the reliability level of a restructured electric power system can be calculated using the availability of the composite power system (HLII) and the reliability of the electricity market (Fig. 3). Two numerical examples showing the application of the proposed method in deregulated power system are described.

The paper has the following structure. A brief introduction to competitive electricity market structure and its performance indices is provided in Section 2; Section 3 describes concepts and techniques of Markov modeling and reliability evaluation; the proposed methodology is studied in Section 4; case studies are presented in Section 5; and finally conclusions are presented in Section 6.

2. Power market structure

Markets are a very old invention that can be found in most civilizations. A market is an environment designed to help buyers and sellers interact and agree on transactions. The development of electricity markets is based on the premise that electrical energy can be treated as a

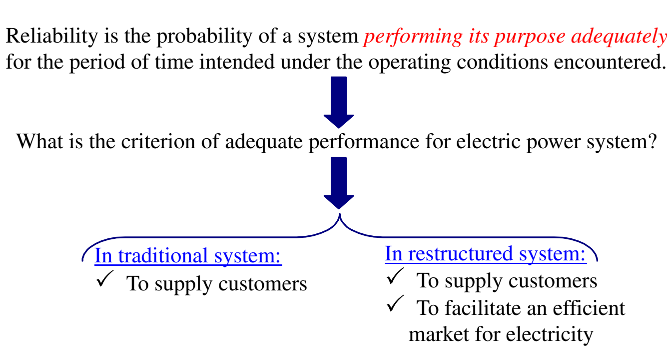

Fig. 1. Reliability definition and its interpretation in electric power system.

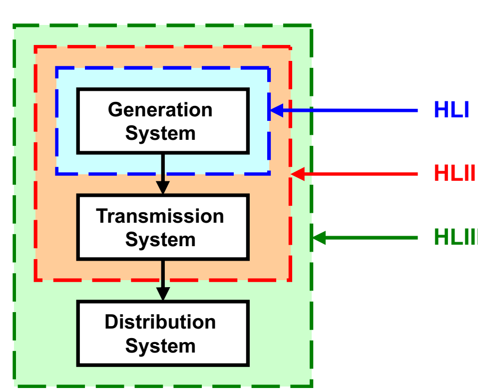

Fig. 2. Electric power system hierarchical level diagram [7].