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Optimal reserve management for restructured power generating systems

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Abstract

This paper presents a technique to determine the optimal reserve structure (reserve providers and the corresponding reserve capacity) for a restructured power generating system (GS). The reserve of a GS can be provided by its own generating units and can also be purchased from other GSs through the reserve agreements. The objective of reserve management for a GS is to minimize its total reserve cost while satisfying the reliability requirement. The reserve management is a complex optimization problem, which requires a large amount of calculations. In order to simplify the evaluation, a complex generating system (CGS) consisting of different GSs and the corresponding transmitting network is represented by its multi-state reliability equivalents. The universal generating functions (UGFs) of these equivalents are developed and the special operators for these UGFs are defined to evaluate the reliability of a particular GS, which has reserve agreements with other GSs in the CGS. The genetic algorithm (GA) has been used to solve the optimization problem. An improved power system-IEEE reliability test system is used to illustrate the technique.

Keywords: Reserve optimization; Reserve agreement; Multi-state system; Reliability; Universal generating function; Reliability equivalent; Genetic algorithm

1. Introduction

There are various engineering systems in the world. One type of these systems is for the resource and energy supply (such as power and gas supply, etc.). Power generating systems in electric industry are this type of systems. In a more broad sense, such engineering systems can be designated as generating systems. The only function of generating systems is to provide reliable and economical resource and energy to their customers. Back up resource or energy, which is designated as reserve in this paper, is commonly used in generating systems in order to provide adequate supply under unexpected system operating conditions such as generating system failures and load growth. In the restructured power system, a generating system can plan its own reserve and can also share reserve with other generating systems according to their reserve contracts. The reserve structure of a generating system should be determined based on balance between the required reliability and the reserve cost. The objective of reserve management for a generating system is to schedule the reserve at the minimum total system reserve cost while maintaining a required level of supply reliability to its customers.

A generating system usually consists of generating units (GUs) with different capacity, cost and availability. Different generating systems are usually connected together through supply network to form a complex generating system (CGS) as shown in Fig. 1. The supply network is designated as transmitting system (TS) in this paper. The objective of the interconnection is to share the reserve. A GS usually signs the reserve agreements with other GSs to increase its reliability and to reduce the reserve cost. A CGS can operate in different states or performance levels due to random failures. The performance levels of a GS in the CGS are usually determined by the number of units, capacity and availability of each unit, transmitting system and reserve agreements with other GSs. The reserve management of a generating system in a CGS therefore is a complex optimization problem, which belongs to system-structure optimization problems addressed in Ref. [1], where binary-state reliability was considered. A CGS and its GSs and TSs are multi-state systems [10] and can be

Abbreviations MSS, multi-state system; MSE, multi-state element; UGF, universal generating function; MSGS, multi-state generating system; MSRP, multi-state reserve provider; MSTS, multi-state transmitting system; PD, performance distribution; LOLP, the loss of load probability; EENS, expected energy not supplied.

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Notation

i	state index for a CGS, $i=1,2,\ldots,K$	p_{mi_t}	probability of MSTS m being the state i_t
p_i	probability of the CGS being in state i	AT_{mi_t}	available transmission capacity of MSTS m associated with the state i_t
w_i	performance level associated with state i	T	total operation period of a MSGS
i_g	state index for a MSGS associated with state i	T^n	time duration for interval n
K_g	number of states for a MSGS	L^n	load level of the MSGS for interval n
p_{i_g}	probability of a MSGS being in state i_g	L_m^n	load level of MSRP m for interval n
AG_{i_g}	available generation capacity of a MSGS associated with the state i_g	CR_m	contractual reserve between the MSGS and MSRP m
i_r	state index for a MSRP associated with state i	CC_m	cost of the reserve capacity of MSRP m
m	MSRP m or MSTS m	EC_m	expected cost of the utilized reserve of MSRP m
K_m^r	number of states for MSRP m	$\varepsilon_{\mathrm{Cm}}$	per unit cost of reserve capacity from MSRP m
p_{mi_r}	probability of MSRP m being in state i_r	$\varepsilon_{\mathrm{Um}}$	per unit cost of the utilized reserve from MSRP m
AG_{mi_r}	available generation capacity of MSRP m associated with the state i_r	LL_i^n	loss of load for MSGS at load level n associated with the state i
AR_{mi_r}	available reserve capacity of MSRP m associated with the state i_r	UR_{mi}^n	utilized reserve of MSRP m at load level n associated with the state i
i_t	state index for a MSTS associated with state i	$U_j(Z)$	UGF for element (or system) j
K_m^t	number of states for MSTS m		

represented using the corresponding equivalents [3,4]. A universal generating function introduced in Ref. [2,5] was used to calculate reliability of a multi-state system. Ref. [6] proposed a system-structure optimization algorithm for multi-state systems. In this algorithm the system components were chosen from a list of available products and were characterized by their performance, availability and cost. The algorithm in Ref. [6] was extended [7] to solve a component redundancy optimization problem for a multi-state system. Selecting redundant elements to maintain a system reliability level was mainly considered in these algorithms. The reserve sharing within a restructured power system through reserve agreements was discussed in Ref. [8]. However, the reserve management of a generating system is a redundant resource problem and the general methods have not been comprehensively developed. The cost of the utilized reserve has not been considered in these techniques.

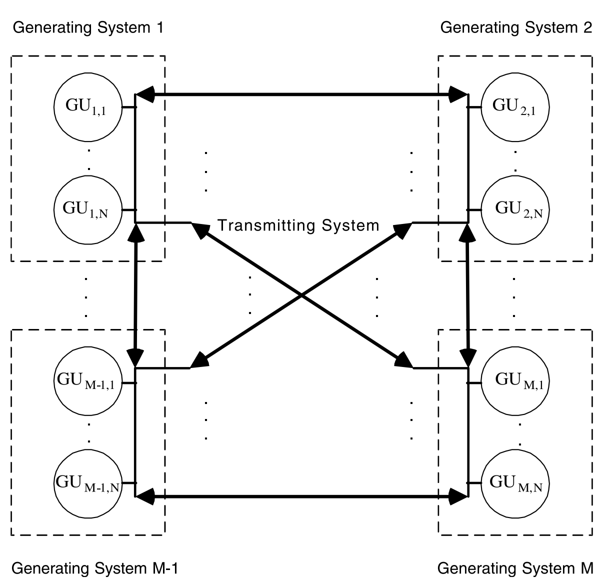

Fig. 1. Complex generating system.

This paper proposes a technique to optimize the reserve structure of a multi-state GS in a CGS. The objective of the problem is to determine the optimal reserve structure (the set of reserve contracts), which can provide a desired level of system reliability to meet the load upon the minimal reserve cost for a GS. The technique is based on the universal generating function (UGF) and the genetic algorithm. The solution comprises reliability and reserve cost (capacity cost and utilization cost) estimates. A power system-IEEE reliability test system is used to illustrate the technique. In Section 4, a GA with the special encoding scheme that considers the structure of reserve capacity and reserve utilization order is developed for the optimization problem. A fast technique based on UGF evaluating the system reliability is presented in Section 3.

2. Models and problem formulation

2.1. Multi-state system models

In order to determine the optimal reserve structure of a specific GS in a CGS, the GS is represented by a MSGS, all other GSs are represented by the MSRPs, and the network between the MSGS and a MSRP is represented by the corresponding MSTS. The equivalent model for the reserve optimization of a MSGS using these equivalents is shown in Fig. 2, in which there are M MSRPs and M MSTSs.

Assume that the MSGS has K_g states and the available generating capacity for each state i_g is AG_{i_g}. These states can be divided into two sub-sets of the normal states (NS) and the contingency states (CS). $\{1,2,\ldots,m_g\}\in\mathrm{NS}$, and