A Study on the Reliability Evaluation of a Transmission System

Seungpil Moon*, Jinboo Choo*, Kyeongho Kim*, Donghoon Jeon * and Jaeseok Choi **

Abstract - Successful operation of power systems under the deregulated electricity market depends on the management of the transmission system reliability. Quantitative evaluation of the transmission system reliability is an important issue. Particularly, the nodal reliability indices can be of value in the management and control of congestion and reliability of the transmission system under the deregulated electricity market. In this study, a method developed for the reliability evaluation of the transmission system is presented. The Monte Carlo methods are used because of their flexibility when complex operating conditions are being considered. The usefulness and effectiveness of the proposed method are illustrated by a case study with the KEPCO system.

Keywords: Reliability of Transmission System, Composite Power Systems, Effective Load Duration Curves.

1. Introduction

A new concept of CMELDC (Composite power system Effective Load Duration Curves) was developed in order to evaluate the nodal reliabilities, to simulate the nodal probabilistic production cost, and to assess outage cost on the composite power system [1]. The reliability of a transmission system can be evaluated with the CMELDC. Methodology for the evaluation is based on the concept that the reliability level of a transmission system is equal to the difference between the reliability levels of the composite power systems (HLII: Hierarchical Level II) and the generation system (HLI: Hierarchical Level I) [1,2].

The method was designed to evaluate the bulk and nodal reliability indices. It is expected that the use of this method will be valuable in the management and control of congestion and reliability as well as determining the optimal reliability level of a real size transmission system under the deregulated electricity market in the future. This paper applies this method to a real size transmission system.

The electric power utilities throughout the world are undergoing considerable change in regard to structure, operation and regulation. Deregulation and competitive pricing will make it possible for electricity consumers to select their supplier based on cost-effectiveness and reliability [3]. The electricity transmission system will be planned, operated and maintained by an independent transmission administrator in the new electric industry structure. Transmission system reliability is an important consideration in system planning and operation. In the past, electric utilities were continuously adding facilities to their systems in order to meet growing customer energy requirements. In most cases, the systems were overbuilt resulting in higher electricity rates for customers [4].

The Korea electricity market is converting to a deregulation situation. The traditional vertically integrated utility structure consisting of generation, transmission and distribution functions has been dismantled and as a result, the monopolistic electricity market has been separated into 6 generation companies. Because the successful operation of electric power systems under the deregulated electricity market depends on the reliability management of the transmission system, an accurate method of transmission system reliability evaluation is very important.

In this paper, the algorithm and usefulness of the method is presented using the KEPCO system.

2. Algorithm

2.1 CMELDC on Composite Power Systems

The basic techniques for an adequate assessment can be categorized in terms of application to segments of a complete power system. These segments can be defined as the functional zones of generation, transmission and distribution systems. The proposed CMELDC at individual load points in a composite power system can be used for load point reliability evaluation at HLII [1, 2, 5, 9].

2.1.1 Effective load at HLII

A new model for nodal effective load at a load point of a composite power system considering the forced outage rates of generation as well as transmission system facilities

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has recently been proposed. The concept of an effective load duration curve at HLII can be defined in a similar way to that at HLI.

Effective load at HLII is also defined by the summation of the original load and the probabilistic load caused by the forced outage of generators and transmission lines. This is formulated as shown in Equation (1).

$$ {}_k x_e = {}_k x_L + \sum_{j=1}^{NS} {}_k x_{oj} \tag{1} $$

where, ${}_k x_e$: random variable of the effective load on the composite power system at load point# k

${}_k x_L$: random variable of the original load at load point# k

${}_k x_{oj}$: random variable of the probabilistic load caused by the forced outage of generators and transmission lines at load point# k

j : number of system states occured at the load point

NS : total number of system states

After considering the generators from #1 to #i, the probability distribution function of CMELDC at load point #k can be calculated as shown in Equation (2).

$$ \begin{aligned} {}_k\Phi_i(x_e) &= {}_k\Phi_o(x_e) \otimes_k f_{osi}(x_{oi}) \\ &= \int {}_k\Phi_o(x_e - x_{oi})_k f_{osi}(x_{oi}) dx_{oi} \end{aligned} \tag{2} $$

where, $\otimes$: the operator meaning convolution integral

${}_k\Phi_o$ = LDC at load point #k

${}_k f_{osi}$: outage capacity pdf of synthesized fictitious generator operated by generators from #1 to #i at load point #k

2.1.2 State Probability

The Monte Carlo simulation methods estimate the indices by simulating the actual process and random behavior of the system. The method, therefore, treats the problem as a series of experiments. In general, if complex operating conditions are not considered and/or the failure probabilities of components are small (i.e., the system is very reliable), then analytical techniques are more efficient. When complex operating conditions are involved and/or the number of severe events is relatively large, Monte Carlo methods are often preferable [6].

The basic sampling procedure can be conducted by assuming that the behavior of each component can be categorized by a uniform distribution under {0,1}. In the case of a two-state component representation, the probability of outage is the forced unavailability of components. It is also assumed that the component outages are independent events.

When *S* denotes the state of the *i*th component and *FOR* is its forced unavailability, a random number generation method, such as the improved prime number multiplicative congruent method, can be used to draw a random number x_i distributed uniformly under {0, 1} as in Equation (3).

$$ S_i = \begin{cases} 0 \text{ (up state)} & \text{where, } x_i \geq \text{FOR}_i \\ 1 \text{ (down state)} & \text{where, } 0 \leq x_i \leq \text{FOR}_i \end{cases} \tag{3} $$

The vector S expresses the state of the system containing components such as generation units, transmission lines, transformers, etc. as follows:

$$ \mathbf{S} = \{S_1, S_2, \ldots, S_i, \ldots, S_t\} \tag{4} $$

When **S** is equal to zero vector, the system is in the normal state. When **S** is equal to nonzero vector, the system is in a contingency state due to component outage(s).

2.2 Arrival Power Evaluation

Since there are several possible solutions when calculating the not served power at a load point for each state, the objective function for minimum not served power must be set up and an optimal solution can be obtained by optimal power flow at HLII. The objective function was established to minimize the not served power at a load point. In this software, transmission line losses are ignored and only the effective power is considered.

Therefore, the problem can be formulated equivalently with parameter λ as shown in Equation (5).

$$ \left. \begin{array}{ll} \textit{Minimize} & \lambda \\ \textit{Subject to} & \\ & \sum_{j=1}^{NB} a_{ij} x_j \leq CG_i \quad i \in B_B \\ & -CT_{l\max} \leq x_l \leq CT_{l\max} \quad l \in B_T \\ & (L_{pk} - x_k)/L_{pk} \leq \lambda \quad k \in B_L \end{array} \right\} \tag{5} $$

where, λ : parameter

a_{ij} : node – element incidence matrix

B_B : set of all buses

NB : total number of branches (generators, transmission lines and load points)

CG_i : capacity of generator #i

L_{pk} : peak load power at load point #k

B_L : set of load buses

$CT_{l\max}$: capacity of transmission line #l, MW

x_l : control variable which means the effective power flow of branch #l

B_T : set of transmission lines

The CMELDC can be calculated by convolving the original load duration curve with the probability distribution function of the not served powers at the load points using Equation (2).

2.3 Nodal Reliability Evaluation in the Composite Power Systems

After considering generators from #1 to #i according to the merit or bidding order in the electricity market, the reliability indices and the CMELDC (${}_k\Phi_i(x)$) at the load point #k of the composite power system are obtained. The reliability indices at the load points, Loss of Load Expectation ($LOLE_{ik}$) and Expected Energy Not Supplied ($EENS_{ik}$) can be calculated using Equation (6) and Equation (7) with CMELDC, ${}_k\Phi_i(x)$.

$$LOLE_{ik} = {}_k\,\Phi_i(x)\,\Big|_{x=AP_{ik}} \tag{6}$$

$$EENS_{ik} = \int_{AP_{ik}}^{AP_{ik}+Lp_k} {}_k\,\Phi_i(x)dx \tag{7}$$

2.4 Bulk System Reliability Indices

While the $EENS_{HLII}$ of the bulk system is equal to the summation of $EENS_k$ at load points, the $LOLE$ of the bulk system is entirely different with the summation of $LOLE_k$ at the load points. As the ELC_{HLII} of the bulk system is equal to the summation of ELC_k at load points, the $LOLE_{HLII}$ of the bulk system can be calculated as shown in Equation (10).

$$EENS_{HLII} = \sum_{k=1}^{NL} EENS_k \quad \text{(MWh)} \tag{8}$$

$$ELC_{HLII} = \sum_{k=1}^{NL} ELC_k \quad \text{(MW/cur.yr)} \tag{9}$$

$$LOLE_{HLII} = EENS_{HLII} \,/\, ELC_{HLII} \quad \text{(pu)} \tag{10}$$

Where, NL: number of load points
$ELC_k = EENS_k \,/\, LOLE_k$ (MW/cur.yr)

2.5 Transmission System Reliability Indices

The reliability indices of the transmission system can be calculated as the difference of reliability indices between HLII and HLI as shown in Equations (11) & (12).

$$EENS_{TS} = EENS_{HLII} - EENS_{HLI} \quad \text{(MWh)} \tag{11}$$

$$LOLE_{TS} = LOLE_{HLII} - LOLE_{HLI} \quad \text{(pu)} \tag{12}$$

3. Case Study (KEPCO System)

Most transmission systems in a monopolistic company are considered overbuilt. The Korea electric power system has been developed, planned and operated by a monopolistic company. Due to the deregulation situation, the necessity of the transmission system reliability evaluation is greatly recognized in order to design and operate the power systems within reasonable reliability levels.

In this paper, 3 case studies are compared. Case study 1 is the basis of this paper. From this study we find that area B is the most reliable zone, area C is the second and area A is the least reliable zone. In case study 2, two transmission lines are added between area A and area C. In case study 3, it is assumed that two transmission lines are added between area A and area B.

Figure 1 shows the reliability zones of the KEPCO system and the added transmission lines in each case study. The rank of the reliability zones results from case study 1.

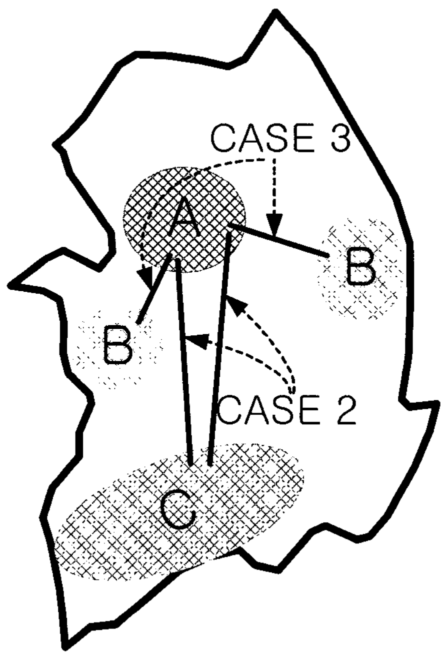

Fig. 1 Reliability zones of the KEPCO system

Table 1 shows the reliability indices of the KEPCO system for each case study. From this table, case study 3 is most reliable in that the transmission lines are added between zones, which have largely different reliability levels. This indicates that the adding of transmission lines between largely different reliability level zones can make the system more reliable.

Table 1 Reliability indices of KEPCO system

	CASE 1		CASE 2		CASE 3	
	LOLE (hr/day)	EENS (MWh/day)	LOLE (hr/day)	EENS (MWh/day)	LOLE (hr/day)	EENS (MWh/day)
HLI	0.07077	54.98	0.07077	54.98	0.07077	54.98
HLII	0.15882	792.48	0.15484	767.35	0.14354	663.65
TL	0.08805	737.50	0.08407	712.37	0.07277	608.67

Table 2 shows that the reliability index of each area is reduced to a greater extent in case study 3. Reliability levels are upgraded considerably by adding transmission lines not only to area A but also to areas B and C.

Table 2 Variations of LOLE at each area

	CASE 1	CASE 2		CASE 3	
	LOLE① (hr/day)	LOLE② (hr/day)	(①-②)/① (%)	LOLE③ (hr/day)	(①-③)/① (%)
Area A	0.16215	0.15905	1.9	0.14638	9.7
Area B	0.14982	0.14641	2.3	0.13593	9.3
Area C	0.15244	0.14738	3.3	0.13804	9.4

4. Conclusions

This paper presents a methodology to evaluate the reliability of a transmission system. The method was designed to evaluate the bulk and nodal reliability indices. It is valuable not only for the management and control of congestion and reliability but also for the determination of an optimal reliability level of a real size transmission system under the deregulated electricity market.

The results of the transmission system reliability evaluation of the KEPCO system using the proposed method are presented. Nodal reliabilities were also evaluated. The Korea electric power system has been developed and operated by the monopolistic company until now. Since the KEPCO system is faced with deregulation situations, the necessity of the transmission system reliability evaluation is recognized as being important. The proposed method could provide useful information when the transmission system should be designed and/or operated with a reasonable reliability level under the deregulated electricity power market.

The nodal reliability indices and local reliability indices can be used in selecting candidates for the expansion planning of the transmission system.

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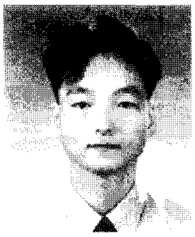

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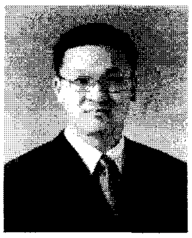

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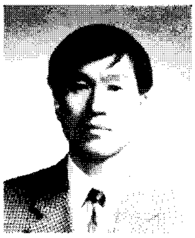

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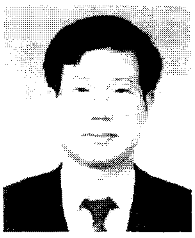

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