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Reliability Contribution Function considering Wind Turbine Generators and Battery Energy Storage System in Power System

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Abstract: This paper presents a study on reliability assessment and new contribution function development of power system including Wind Turbine Generator(WTG) combined with Battery Energy Storage System(BESS). This paper develops and proposes new reliability contribution function of BESS installed at wind farms. The methodology of reliability assessment, using Monte Carlo Simulation (MCS) method to simulate sample state duration, is proposed in detail. Forced Outage Rate(FOR) considered probabilistic approach for conventional generators is modelled in this paper. The high penetration of wind power can make risk to power system adequacy, quality and stability. Although the fluctuation of wind power, BESS installed at wind farms may smooth the wind power fluctuation. Using similar size model system as Korea power system, a case study of reliability evaluation and new proposed contribution function of power system containing WTG combined with BESS is demonstrated in this paper, which would contributes to BESS reliability contribution and assessment tools of actual power system in future.

Keywords**:** Wind Turbine Generator(WTG), Battery Energy Storage System(BESS), Monte Carlo Simulation(MCS), Reliability evaluation, ESS reliability contribution

1. INTRODUCTION

Since the Paris Agreement on Dec. 12, 2015, sources of new renewable energy generation have been expected to be incorporated into the power system more rapidly worldwide. However, such sources of new renewable energy generation exhibit a high variability in output, which requires the development of a technology to reduce it. One of the technologies that are receiving people's attention now is a bonding technique that relieves variability by installing Battery Energy Storage System (BESS)(herein, called as "ESS" for convenience) into the sources of new renewable energy generation showing a high variability in output and performing both charge and discharge properly. However, there are few studies on probabilistic reliability estimation in the power system with sources of new renewable energy generation and energy storage system combined both internally and externally, compared to in other fields. So far, relevant studies include a study on reliability from the aspect of adequacy when ESS is installed into a wind farm by using Monte Carlo Simulation (MCS) by professors Po Hu and Rajesh Karki in Saskatchewan University, Canada and professor Roy Billinton's team in 2009, a study on reliability by using an analytical method by doctor Z. Y. Gao in China and professor Peng Wang's team in Singapore in 2010 and a study on reliability when ESS was installed into microgrid by professor Carmen L. T. Borges' team in Brazil in 2011. Internally, the only relevant study is a recent fundamental research on reliability when ESS was installed into a wind farm by these authors.

This study aims to propose reliability evaluation models and methods in the power system by using Monte Carlo Simulation (MCS) if linked with the existing power system in more detail and develop a contribution evaluation function to reveal the value of ESS from the aspect of reliability. By installing energy storage system into multiple wind farms, the fear of having to meet the demand from the aspect of reliability is dispelled by relieving a rapid variability in a wind power generator, because of with the increasing number of wind generator with a high variability in output. There is an increasing demand for incorporation of energy storage system into the power system to reduce the variability and technical development on the effects from the aspect of reliability is being emphasized. Furthermore, it identifies the usefulness of the developed ESS contribution evaluation function compared with the power system model similar to the size of Jeju system (hereinafter, called as power system model similar to Jeju sysem).

2. PROBABILISTIC RELIABILITY EVALUATION OF POWER SYSTEM BY MONTE CARLO SIMULATION

2.1 Generating the operating history for virtual Generator with λ and μ parameters

1) Formulation of TTF and TTR

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The concept that CG are calculating FOR(Forced Outage Rate) by two probabilistic working models has a long history. However, to evaluate the reliability of MCS, it is necessary to unravel MTTF and MTTR, two parameters that cause random numbers in (4) and (5) and constitute the FOR of two working models by using FOR and reconstruct virtual operation history for the generators with a long history. At this time, TTR should be reconstructed in order, next to TTF.

$$TTF_{i,k} = -MTTF_i \ln U_k = -\frac{1}{\lambda_i} \ln U_k \tag{4}$$

$$TTR_{i,k} = -MTTR_i \ln U_k^{'} = -\frac{1}{\mu_i} \ln U_k^{'} \tag{5}$$

where,
λ_i: Failure rate of the ith Generator
μ_i: Repair rate of the ith Generator
U_k, $U_k^{'}$: Two uniformly distributed random number between [0, 1] at kth state

2) Total generation capacity Calculation

$$TG_k = \sum_{i \in \Omega_{NG}} G_i \times ISK_{i,k} \tag{6}$$

$$ISK_{i,k} = \begin{cases} 1 & k \in \Omega_{\mathrm{TTF}_i} \\ 0 & k \in \Omega_{\mathrm{TTR}_i} \end{cases} \tag{7}$$

where,
Ω_{NG}: Total Generators, NG: Generator Set
TG_k : Total Generation Capacity at kth state [MW]
$G_{i,k}$: The ith generator Capacity [MW]
$ISK_{i,k}$: Probability of the ith generator at kth state
Ω_{TTFi}: TTF set of the ith generator
Ω_{TTRi}: TTR set of the ith generator

2.2 Probabilistic output prediction model of WTG

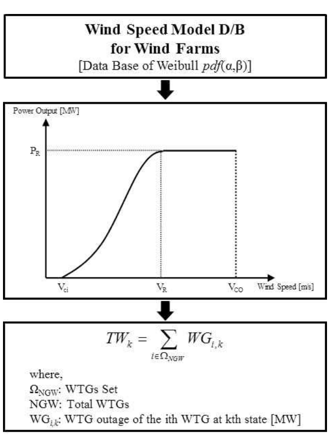

Fig. 4. Total generation model of WTG proposed in this paper for MCS

Globally, wind speed is found to be indicated in Weibull probability distribution close to normal probability distribution. Indeed, as a result of analyzing the distribution of wind speed from 1998 to 2007 in Jeju Island, Korea, it was obtained that scale(α)=3.42 and shape(β)=1.85. In this respect, this study builds a database of the values of α and β, scale parameter and shape parameter, respectively assuming that wind speed for each wind farm is indicated in Weibull probabilistic distribution. To do so, this study uses MCS to create a long-term artificial history of wind speed and calculate the outputs of each wind power generator in conjunction with the characteristic curve of output of WTG at kth state and combine them to calculate total output TW_k[MW]. Fig. 4. depicts wind power generation output calculation method used in this study. For reference, this study models one equivalent wind power generator for each wind farm.

2.3 Reliability Indices calculation by MCS(Monte Carlo Simulation) method

If combining all sums of outputs(supply)($TCAP_k$=TG_k+TW_k) from the virtual operation rewritten by considering FOR of CG and WTG and uncertainties of wind speed in order to use MCS, it is as shown in Fig. 5. On the other hand, if formalizing the differences, it is as shown in (9).

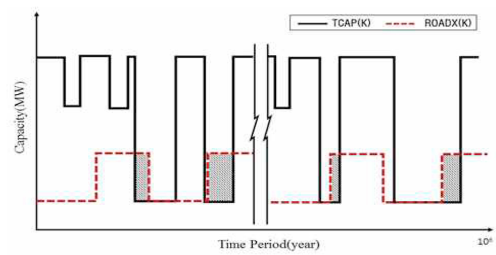

Fig. 5. An example of load for each state and CG's probabilistic output(TG_{ck})

In Fig. 5, the overlapped portion due to lack of power supply rather than load indicates 'demand not served.' Therefore, Energy Not Supplied (ENS_k) at kth state is formalized in (10) and representative indicators of reliability, Expected Energy Not Served(EENS) and Loss of load Expectation (LOLE), are obtained from (11) and (12), respectively.

$$SRP_k = TG_k + TW_k - PD_k \tag{9}$$

$$ENS_k = \begin{cases} SRP_k & SRP < 0 \\ 0 & SRP \geq 0 \end{cases} \tag{10}$$

$$EENS = \sum_{k=1}^{NSS} ENS_k \,/\, NY \tag{11}$$

$$LOLE = \sum_{k=\Omega^-} \Delta t \,/\, NY \tag{12}$$

where,
SRP: Supply Reserve Power[MW](if SRP is (-), Energy Not Served)
TG: Total Generator capacity[MW], TW: Total WTGcapacity[MW]
NSS: Total states(=NY×NS), NS: States of each year in MCS
NY: Years of MCS(Monte Carlo Simulation)

3. ESS OPERATION MODEL

In this study, it targets HLI(Hierarchical Level I), there are wind power generation farms at multiple places, ESS is installed at one site only, and it introduces a proper control method for charging and recharging ESS. Fig. 6 shows what was used in this study.