풍력발전기의 Capacity Credit 추정에 관한 연구

오 량, 박정제, 최재석
경상대학교

Analysis of the Capacity Credit of Wind Farms

Liang Wu*, Jeongje Park*, Jaeseok Choi*
Gyeongsang National University*

ABSTRACT- Because of being environmentally friendly, renewable energy resources has been growing at a high rate. Wind energy is one of the most successfully utilized of such sources for producing electrical energy. Due to the randomness of wind speed, wind farms can not supply power with a balanceable level as well as conventional power plants. The reliability evaluation of wind power is more and more important. Capacity credit is used to estimate the capacity credit of power systems including wind farms. This paper presents a method of capacity credit calculation for a power system considered wind farms and shows how it gets study on an actual power system (the Jeju Island power system). The paper describes the step of capacity credit calculation and presents test results, which indicate its effectiveness.

1. Introduction

In modern world, the utilization of renewable resources such as wind, solar have received a considerable attention in the recent year. This is due to the fact that conventional resources such as oil, coal are reducing and ejective green house gases have impacted the environment and these renewable energy units are environmentally friendly. And it has been proved that wind energy is a faster growing and most successful renewable energy with high capacities, generation costs of WTG (wind turbine generator) are becoming competitive with conventional energy resources. Unfortunately wind come from nature, people can not control wind resource. Power generated from wind turbine generator (WTG) depends on the wind speed which fluctuates randomly. All appearance, the reliability is lower than conventional generators. So how many wind resource can be utilized is most important point. The concept of capacity credit was suggested. It remains the preferred metric when performing wind generation expansion studies. The capacity credit was derived based on indices of reliability evaluation, loss of load expectation (LOLE)[1]. In this paper, Convolution integral by using a multi-state model will the parameters of the reliability evaluation of wind farms. In the case study, the existing power system consists of all conventional generators. It is considering wind generation expansion and wants to evaluate the capacity credit of the added wind farms. An application of the proposed capacity credit based on the ELCC(effective load carrying capability) and the reliability probabilistic calculation by using a multi-state model will be presented in the below sections.

2. What is capacity credit?

Capacity credit estimates wind power plants to help generating companies, utility planners, and other decision-makers evaluate this intermittent resource. Capacity credit is the level of conventional generation that can be replaced with wind generation. To perform such an analysis, it is important to define the way in which one type of resource can be substituted for another. Most analysts prefer basing such a trade-off on a reliability measure. A common measure of system reliability is loss-of-load expectation (LOLE). The LOLE is an indication of the statistically expected number of times within a given time period that the system could not provide for customer load. If a given level of wind-generating capacity can be substituted for conventional capacity, holding the reliability level constant, then we can obtain a measure of wind plant capacity credit.

Effective load-carrying capability (ELCC) is a way to measure a power plant's capacity credit based on its influence on overall system reliability. When a new generating unit is added into a power system, the ELCC of the unit is the amount of extra load that can be served while keeping a suitable level of reliability. The suitable level is the LOLE of the system before addition of the new generating unit. Thus, The LOLEs of existing and potential systems are equal. The concept of ELCC is Introduced by Eq. 1~4.[1]

$$LOLE_E = LOLE_P \tag{1}$$

$$\sum_{i=1}^{n} P\left(X_E > C_E - L_i\right)\cdot t_i = \sum_{i=1}^{n} P\left(X_P > \left(C_E + C_A\right) - \left(L_i + \Delta L\right)\right)\cdot t_i \tag{2}$$

$$ELCC = \Delta L \tag{3}$$

$$\text{capacity credit} = \frac{\Delta L}{C_A} \times 100\% \tag{4}$$

Where,

- P(XE>CE-Li) and P(Xp>(CE+CA)-(Li+△L)) are the loss of load probabilities(LOLPs) of the existing and potential systems.
- The LOLP is the LOLE dividing the period.
- △L is the extra load that can be served by the additional generation.
- C_A is the added generator's capacity.

In a power system added wind farms, due to the nature of wind, the reliability of wind farms is lower than conventional power plants'. All the extra added wind power can not supply load demand fully. The ELCC is more impotent for reliability evaluation of wind farms.

For wind farms, the method which obtains LOLE is different with conventional power plants'. A two-state model can not calculate the reliability evaluation indices accurately. A multi-state model should be used.

3. Reliability Probabilistic Evaluation of Wind Farms

Because wind speed does not maintain a specified stable level, a two-state model is not suitable for modeling WTGs for the same purpose. The multi-state model introduced in [2]-[5]. Due to the linear change of wind, the multi-state model for the power output of a WTG takes the form of a chain. A power output model of a WTG is combined with a wind speed model to obtain a multi-state model. Reference [3] presented a mathematical model for wind power output and wind speed in detail. The multi-state model based on convolution integral is used to obtain the indices of reliability evaluation for WTG.

The method obtaining reliability probabilistic indices have been used extensively for generation expansion is introduced in reference [7].

This multi-state model represents the probability corresponding to any power output of the WTG, which is essential for the evaluation of the wind farm reliability. Fig.1 is the flow chart describing the steps to evaluate the reliability of a power system including WTGs is given.

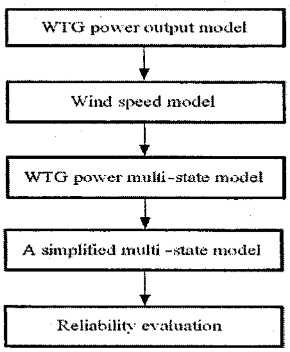

Fig.1 The step-by-step process for evaluating the reliability of a power system involving WTGs

4. Case Study

The approach described earlier was implemented on the power system of Jeju, which is the largest tourist island in Korea. Strong wind forces are mostly seen on the northwest coastal area where winter monsoon has great influence, while the southeast coastal area has a relatively weak wind. It is because of the good wind conditions in island that wind farms have become a part of its power system.

The data of Jeju Island power system are introduced in table 1.

Table 1 Data of Jeju Island power system

	Name	Type	C[MW]	Number	FOR
1	NMJ3	T/P	100	2	0.012
2	JJU1	T/P	10	1	0.015
3	JJU2	T/P	75	2	0.012
4	HNM1	G/T	35	2	0.013
5	HNM1	S/T	35	1	0.013
6	JJU3	D/P	40	1	0.018
7	NMJ1	D/P	10	4	0.018
8	HVDC	DC	75/150	2	0.010/0.028
9	JCN1	WTG	20	1	-
10	SSN2	WTG	30	1	-
11	HWN3	WTG	50	1	-
Total			945	18	-

Data related to three wind farms are constructed in three different locations; JoCheon (JCN), Sungsan (SSN) and Hangwon (HWN) are given in Table 2.

Table 2 Data of JCN, SSN and HWN wind farms

Wind			
Wind farm	JCN-WF	SSN-WF	HWN-WF
Peak speed	35m/sec	40m/sec	45m/sec
Mean speed	6.4 m/sec	7.6 m/sec	8.5m/sec
Standard deviation	9 m/sec	10 m/sec	11 m/sec
WTG			
WTG capacity	20MW	30MW	50MW
Cut-in speed(V_{ci})	5 m/sec	5 m/sec	5 m/sec
Rated speed(V_R)	14 m/sec	15 m/sec	16 m/sec
Cut-out speed(V_{co})	25 m/sec	25 m/sec	25 m/sec

Combining the wind power output model and the wind speed model results the out power and the corresponding probability. According to proposed approach, this multi-state model is simplified. The outage capacity probability distribution function (OCPDF) considering a 5-state, a 7-state and an 11-state model of the three wind farms are obtained. [7]

In this system including CG and WTG, the some different generators can be incorporated very easily to obtain the indices of the system reliability evaluation by using convolution integral.

In Jeju Island power system, the hourly average loads are collected to obtain the daily load duration curve (DLDC) is presented in Fig.2.

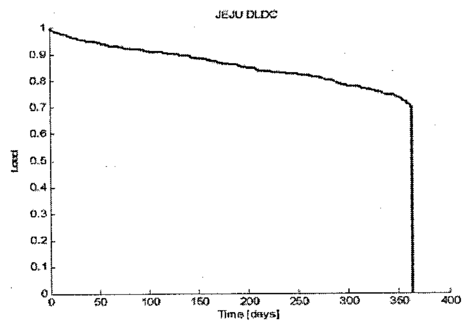

Fig.2 Daily peak load duration curve of Jeju Island power system

The total capacity including conventional generators and wind turbine generators is 945MV, and the peak load is 681MV. Table 3 shows that the reliability results in Jeju Island power system.

Table 3 Indices of Jeju Island power system

LOLE[days/year]	0.44
EENS[MWD/year]	17.10
EIR	0.99992

Power system reliability is very sensitive to changes in the system peak load. This is reflected in the results given in Fig.3 which shows the variation of the LOLE corresponding to different peak load levels.

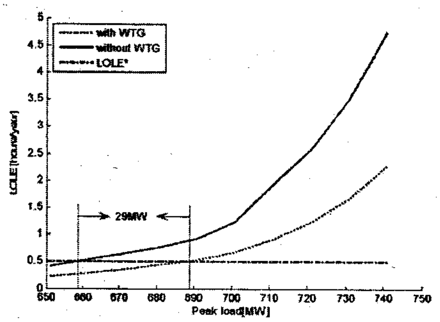

Fig.3 LOLE for different peak load levels

In jeju island, the designed reliability level is 0.5 days/year. The extra load of the additional generation of WTG is approximately 29MW. The capacity of the added wind farms is 100MW. The above data are used in Eq.4; therefore the capacity credit of the WTG is about 29%.

The reliability of the added wind farms that the capacity is 100MW is equal to conventional power plants that the capacity is 29MW. So conventional power plants that the capacity is 29MW can instead of the add wind farms. It is the purpose which is people researching the capacity credit.

All appearance, capacity credit has a relationship with different designed reliability levels. We change different designed reliability levels, we obtain the ELCC corresponding with the different designed reliability levels, and it is presented in Fig.4.

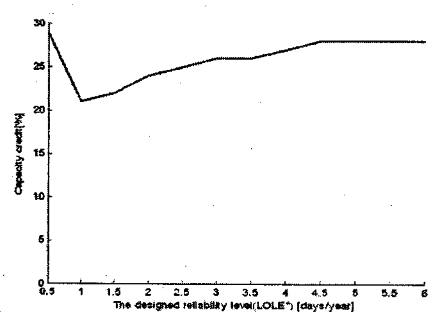

Fig.4 Capacity credit according to changing of designed relibility level (LOLE*)

In Fig.13 we can find when the designed reliability level is 0.5, the capacity credit is the highest one. While the designed reliability level is 1, the capacity credit is the lowest. When the designed reliability is From 1 to 6, the curve is moving up stage by stage, finally the capacity credit keeps on 28%.

In the developing country, because the scale building power system is not larger and better than the developed country, the designed reliability level can not be set enough low. But the capacity credit is similar with developed countries. In my apprehension the influence of designed reliability level on capacity credit is not obvious. Capacity credit of wind farms do not only depend on the designed reliability level of the given location. Wind speed, wind penetration level and the place that wind farms are built is more important.

5. Conclusion

This paper introduces an essential capacity credit and a process of capacity credit calculation. The calculation process also includes a process of reliability probabilistic evaluation. Due to the nature of wind, wind farms' reliability is lower than conventional power plants'. Capacity credit of wind farms should be regarded more and more. A multi-state model for WTGs is used in a reliability evaluation of power system that includes wind farms. This model reflects the variation of wind more accurately than the two-state model. Although the capacity of WTG is high, due to the effect of wind speed variation for reliability evaluation of WTG, the actual capacity is lower. The capacity credit can show us How many wind farms should be build must consider the actual capacity of WTG.

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