CHAPTER 4

Reliability Contributions of Renewable Generation

4.1 Introduction

Renewable energy sources are generally small in size, abundant, and intermittent. The intermittent behavior introduces several challenges including power system control, stability, and reliability. Given the intermittent behavior, the output of renewable power plant would be able to supply or carry the load less than the output of conventional sources. In addition, conventional power plants are dispatch-able because of fuel availability, while renewable power plants may not be dispatch-able given that their energy sources vary from time to time either on an hourly basis or a seasonal basis.

In terms of generation reliability, what is the equivalence between conventional capacity and renewable capacity? In other words, how much renewable capacity is needed to replace conventional capacity while generation reliability is maintained?

Hence, this chapter presents the reliability contribution of renewable generation in term of the capacity credit and the effective capacity. This is in order to correlate between conventional capacity and renewable capacity. The capacity credit is described in Section 4.2 and the concept of effective capacity is proposed for evaluating generation reliability of renewable power plant in Section 4.3.

4.2 Capacity Credit

Capacity credit was proposed to determine the contribution of generating unit on supply adequacy. There are several definitions and methods to compute capacity credit such as Equivalent Firm Capacity (EFC), Effective Load Carrying Capability (ELCC), Equivalent Conventional Power Plant (ECPP) and Guaranteed capacity (GC) [Amelin, 2009; Amelin and Söder, 2010]. The most well-known definition is the ELCC [Garver, 1966]. Recently, the EFC [Haslett and Diesendorf, 1981] and the GC [Amelin and

Söder, 2010] were just introduced. Capacity credit is computed by using statistical methods and depends on a set of data so that the result may change over time. Hence, the actual contribution of a generating unit on a particular period of time may deviate significantly.

It is practically impossible to validate a capacity credit of a generating unit because the definitions are expressed as a comparative or relative term, i.e. it is not individual property of a generating unit but depends on generation system at a given point in time. Although the value of capacity credit is time dependent, but it can effectively indicate how a generating unit affects the generation reliability.

4.2.1 Equivalent Firm Capacity

The EFC compares the capability to improve the reliability of a unit with fictitious unit that is 100% reliable.

The computational concept of the EFC can be visualized by using the ILDC as shown in Figure 4.1. Suppose the capacity of all units (system capacity) is *S* and the capacity of the unit of interest is *C*. The solid line illustrates the ELDC of all units, while the dash line illustrates the ELDC of all units except the unit of interest. By projecting from the system capacity *S*, the probability that the equivalent load exceeds the capacity of all units is *R*. The equivalent load of all units except the unit of interest which has the same risk of power deficit *R* is *X*. So the EFC of the unit of interest is *X*-(*S*-*C*).

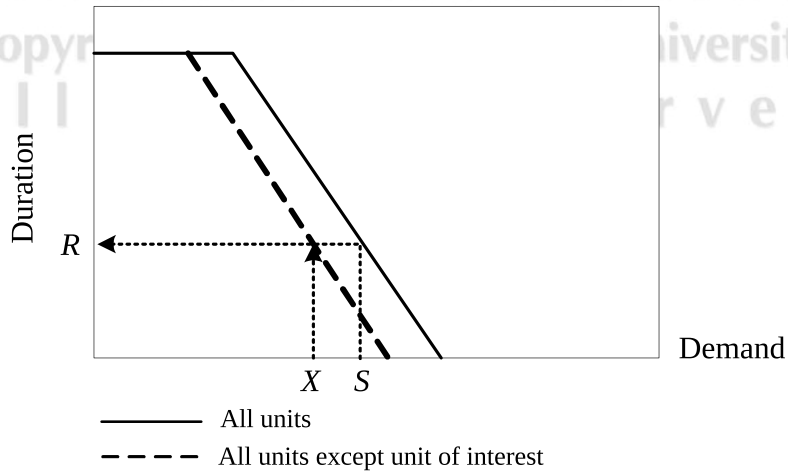

Figure 4.1 Illustration of equivalent firm capacity.

4.2.2 Effective Load Carrying Capability

The computational concept of the ELCC can be visualized by using the ILDC as shown in Figure 4.2. Suppose the capacity of all units (system capacity) is S and the capacity of the unit of interest is C. The solid line illustrates the ELDC of all units, while the dash line illustrates the ELDC of all units except unit of interest. By projecting from the system capacity less the capacity of the unit of interest $S - C$, the probability that the equivalent load exceeds the generation capacity of all units except the unit of interest is R, which can be considered as reliability level or risk of capacity deficit. When the unit of interest is added to the system, the reliability level would increase and the risk of capacity deficit would decrease so that the system could supply more load. The ELCC of the unit of interest is thus defined as the largest (peak) load shift, i.e. to be added to the existing system without altering the reliability level. Therefore, the contribution of the unit of interest on generation reliability can be determined from the ELCC, which can be seen from Figure 4.2 that the ELCC is less than the capacity of the unit of interest.

4.2.3 Equivalent Conventional Power Plant

The ECPP definition is based on a comparison with baseline unit as EFC but the baseline unit is not 100% reliable. The computation of ECPP is essentially the same, but the ECCP will be higher than the EFC.

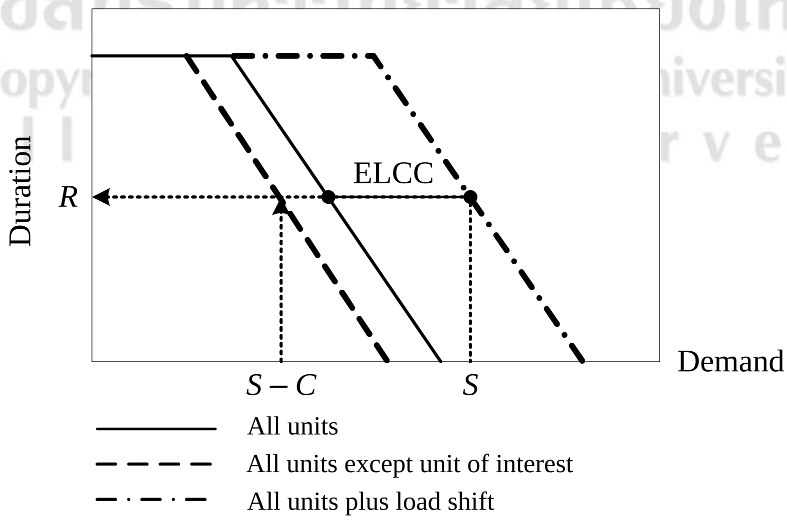

Figure 4.2 Illustration of effective load carrying capability.

4.2.4 Guaranteed Capacity

The GC is the highest load level that can be supplied with an arbitrarily chosen probability.

The computational concept of the GC can be visualized by using the ILDC as shown in Figure 4.3. The solid line illustrates the ELDC of all units, while the dash line illustrates the ELDC of all units except unit of interest. By projecting from an arbitrarily chosen probability *R* (the risk of capacity deficit), The capacity level that will be exceeded with *R* of ELDC of all units is *X1* and the capacity level that will be exceeded with *R* of ELDC of all units except the unit of interest is *X2* then the GC is equal to *X1*-*X2*.

4.3 Effective Capacity

It is proposed to define an effective capacity (EC) to quantify the contribution of renewable capacity on generation reliability. The value of EC would be equal or less than unity. For instance, when the EC of renewable capacity is 0.8 or 80%, it implies that 1 MW of renewable capacity is equivalent to 0.8 MW of conventional capacity given the same level of generation reliability. Thus, capacity credit can be calculated by multiplying the EC with the installed capacity of renewable power plant.

Generally speaking, a unit of interest is a renewable unit with installed capacity, *RK* and a benchmark unit is a conventional unit with installed incapacity, *CK*.

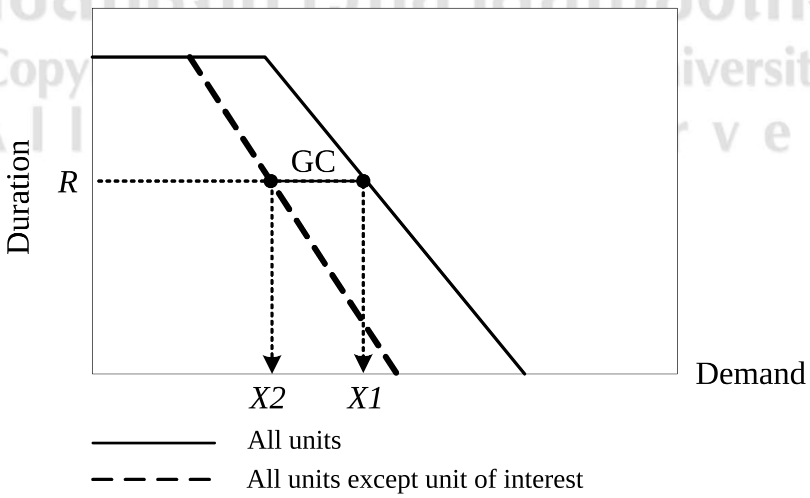

Figure 4.3 Illustration of guaranteed capability.

The FOR of renewable unit is considered from mechanical availability and intermittent effect. Conventional unit, served as a benchmark, is not perfectly reliable so that typical value such as 5% FOR is assumed. It is also assumed that the installed capacity of the benchmark unit is small so that it can be comparable to typical size of renewable energy source.

The computational steps of the EC can be explained as follows. Firstly, the relationship between generation reliability index (expressed by LOLP) and peak demand is plotted without the unit of interest. Secondly, LOLP at the existing peak demand is noted. The existing LOLP would be higher than the target LOLP because the unit of interest has not been included into consideration. Then, the unit of interest is added and the new curve is plotted. The new curve should be lower than the old curve because the generation reliability is improved. The new (lower) value of LOLP at the existing peak demand is set as the target LOLP. Alternatively, the target LOLP may even be lower, if desired. In so doing, additional capacity from the unit of interest is needed. Next, the unit of interest is replaced by the benchmark unit with small incremental capacities until the LOLP equals or less than the target value (shown as shaded area in Figure 4.4). The Effective Load Carrying Capability (ELCC) is computed at the target LOLP. It should be emphasized that the ELCC in this work is different from the original definition [Garver, 1966] which computes the ELCC at the reliability level before adding capacity. Finally, the EC of the unit of interest can be computed by using two definitions [Chaiamarit and Nuchprayoon, 2014a].

The first definition considers the EC from the ratio of the installed capacity of the benchmark unit to the installed capacity of the unit of interest, as shown in (4.1).

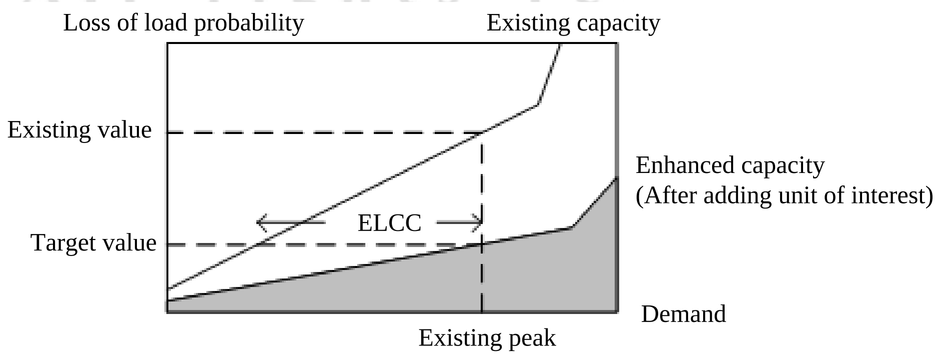

Figure 4.4 Effective load carrying capability.

$$\mathrm{EC_I} \triangleq CK/RK. \tag{4.1}$$

The second definition considers the EC from the ratio of ELCC to the installed capacity of the unit of interest, as shown in (4.2).

$$\mathrm{EC_{II}} \triangleq \mathrm{ELCC}/RK. \tag{4.2}$$

The difference between the two definitions is thus on the nominator. Note that the first definition is similar to capacity credit [Zhang, Li and Zhou, 2010] and the second definition is similar to the equivalent capacity rate [Wen, Zheng and Dongham, 2009; Caralis and Zervos, 2010]. It can be mentioned that the EC is dependent of the FOR, capacity size, and target value of generation reliability index.

4.4 Chapter Summary

This chapter presents the concepts of capacity credit and effective capacity. There are various definitions and methods to compute capacity credit. In this research, two definitions of effective capacity are proposed to evaluate the contribution of renewable energy unit.