Calculation of Electrical Energy Demand vs. Peak Renewable Capacity

1. Introduction

In the past, the SWAT RTTF has proposed studying a "20% and "40%" power flow scenario cases. There is a lot of confusion on what these stated percentages represent. They were intended to represent the percentage of total renewable potential in the SWAT area. This becomes somewhat confusing when one wants to compare the power flow study assumption to the RES goals that states have. There are a number of assumptions one would have to make to convert the percentage number to a number comparable to an RES goal (e.g. renewable generation capacity factor, load demand factor, …) Therefore it is proposed that: **a X% percent SWAT RTTF study will represent the scenario in which X% of the study area energy demand is served from renewable resources**. Hopefully this will address any confusion that the SWAT RTTF members have on what the power flow cases actually represent, as compared to state RES goals. Using the proposed meaning of "X%" study, the formerly used 20% and 40% power flow cases would now be refereed to (approximately) *13.5% and 25% cases*. Therefore, it might be beneficial to readdress the study percentages before power flow study work is performed.

In anticipation of the SWAT RTTF power flow study, an elementary calculation method is developed herein that relates a "rated" capacity output of the renewable energy zones to a percent of demand energy served (via renewable resources). In principle, this calculation takes the percentage (of energy served from renewable resources) that state governments determine as their RES goals and converts it to a MW amount of renewable resources located in associated renewable energy zones (e.g. results from the ARRTIS work).

2. Nomenclature

E_i^r - annual energy served from renewable resource for zone i

E_i^d - annual electrical system energy demand for zone i

8760 - number of hours in 1 year

CF_i^r - Annual capacity factor of renewable resources in zone i

LF_i^d - Annual demand load factor for zone i

P_i^{ren} - Peak output from renewable resources in zone i

P_i^{demand} - Peak load demand in zone i

$\%_i^r$ - Percent of energy demand served from renewable resources.

3. Basic Calculations

Assume that a power system is comprised of "zones" which represent areas in which load and renewable generation exist. The amount of annual energy demand in each zone is expressed as:

$$E_i^d = 8760\left(LF_i^d P_i^{demand}\right) \quad MWhr. \tag{1}$$

where:

P_i^{demand} is the annual peak load demand in zone *i*, and LF_i^d is the annual demand load factor for zone *i*.

Equation (1) represents the energy demand, and the type of this energy can come from any fuel source. The amount of energy that is served from renewable resources is determined by

$$E_i^r = 8760\left(CF_i^r P_i^{ren}\right) \quad MWhr \tag{2}$$

where:

CF_i^r is the annual capacity factor of renewable resources in zone *i*, and P_i^{ren} is the peak output from renewable resources in zone *i*.

The percent amount of energy served from renewable resources in a zone is

$$\%_i^r = 100\frac{E_i^r}{E_i^d} = \frac{100\left(CF_i^r P_i^{ren}\right)}{LF_i^d P_i^{demand}} \quad percent\,, \tag{3}$$

with the peak capacity of renewable energy served in a zone

$$P_i^{ren} = \frac{\%_i^r LF_i^d P_i^{demand}}{100\left(CF_i^r\right)} \quad MW\,. \tag{4}$$

Using Equations (3,4), one can easily calculate the amount of peak renewable energy served from one particular zone to a zone with energy demand.

If it is necessary to serve renewable energy from several zones to a particular load zone, the amount of renewable energy served is the summation of the energy of each renewable energy zones,

$$\%_i^r E_A^d = \sum_{i=1}^{n} E_i^r = 8760\sum_{i=1}^{n} CF_i^r P_i^{ren} \tag{5}$$

where:

n is the number of renewable energy zones serving energy to the demand in zone A.

Equation (5) gives a foundation in calculating the amount of installed renewable generation capacity for a group of several zones that supplies power to a particular load pocket zone. However, in order to determine the installed capacity, other criterion needs to be determined in order to solve (5). The criteria can come from a variety of different assumptions. For example:

- equal amount of renewable generation in each zone
- zonal installed renewable capacity is based on the percentage amount of the total potential of renewable resources
- financial considerations.

4. Example

Assume that there are four areas of a system that comprise of the load demand and location of the renewable resources that serve that demand. This is illustrated in Figure 1.

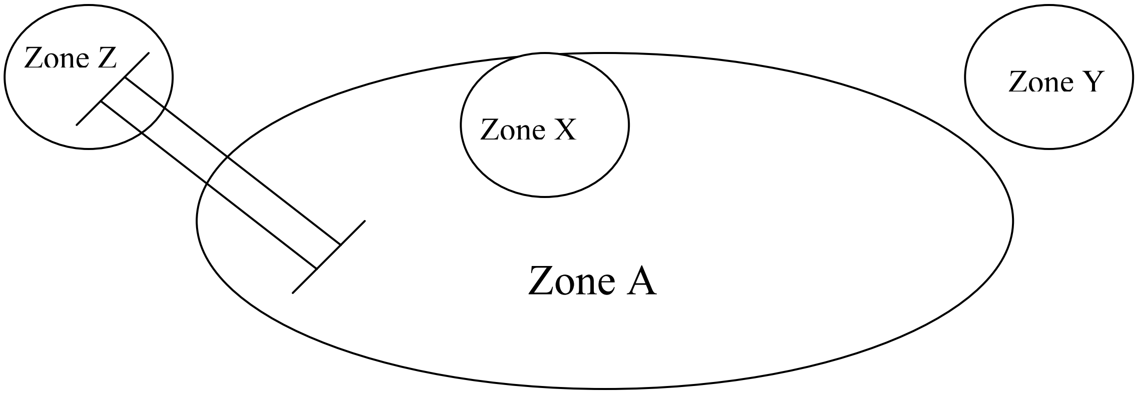

Figure 1

Zone A has a peak demand of 20,000 MW, load factor of 0.50, with renewable resources located within Zone A called Zone X.

Zone X has a renewable potential of 10,000 MW with adequate transmission available to serve the load, but at an average generating capacity factor of 0.50.

Zone Y has a renewable energy potential of 40,000 MW, with an average generating capacity factor of 0.45, however long distance transmission circuits are needed to bring the resources to the load in Zone A.

Zone Z is a pocket of renewable energy that is located outside of Zone A, and can serve the load in Zone A though already existing long distance transmission circuits. This zone has an energy potential of 30,000 MW with a capacity factor of 0.35.

Given that the LSE in Zone A wants to have 20% percent of its energy supplied from renewable energy resources, what is the amount of peak renewable energy needed from Zones X, Y, and Z, for each of the following scenarios:

A. The LSE in Zone A does not want to build new transmission circuits, nor wants to import renewable energy resources from outside the area.

In this case, Zone Y has no existing transmission circuits, and Zone Z is located outside of Zone A. Therefore, the only renewable energy resources that Zone A wants to serve its load exist in Zone X. Therefore, the installed capacity of the renewable resources in Zone X needed to serve 20% of the energy in Zone A is:

$$P_X^{ren} = \frac{\%_A^r LF_A^d P_A^{demand}}{100\left(CF_X^r\right)} = \frac{20 * 0.50 * 20000}{100 * 0.50} = 4000 \quad MW$$

B. The LSE in Zone A wants to consider renewable resources from virtually anywhere, and is able to build transmission to any renewable resource pocket within a reasonable distance from its area.

In this case, renewable energy can be served to Zone A from Zones X, Y, and Z. Since each of the three zones contribute renewable energy to Zone A, the formulization of the expected generation from Zones X, Y and Z are calculated in a different manner:

With 20 percent of energy served to come from renewable resources, the amount of renewable resource energy served is:

$$0.20E_A^d = E_X^r + E_Y^r + E_Z^r$$

$$(0.20)8760\left(LF_A^d P_A^{demand}\right) = 8760\left(CF_X^r P_X^{ren}\right) + 8760\left(CF_Y^r P_Y^{ren}\right) + 8760\left(CF_Z^r P_Z^{ren}\right)$$

$$(0.20)\left(LF_A^d P_A^{demand}\right) = \left(CF_X^r P_X^{ren}\right) + \left(CF_Y^r P_Y^{ren}\right) + \left(CF_Z^r P_Z^{ren}\right)$$

$$(0.20)(0.50 * 20000) = 0.50P_X^{ren} + 0.45P_Y^{ren} + 0.35P_Z^{ren}$$

$$2000 = 0.50P_X^{ren} + 0.45P_Y^{ren} + 0.35P_Z^{ren} \tag{6}$$

From Equation 6, constraints need to be made on the peak renewable energy from each zone in order to solve equation 6. Assume the following two scenarios.

i. Equal installed capacity energy generation from each zone.

In this case, the peak renewable energy served from each zone is equal:

$$P_X^{ren} = P_Y^{ren} = P_Z^{ren} = P^{ren} \tag{7}$$

Substitution of equation (7) into (6)

$$2000 = 0.50P^{ren} + 0.45P^{ren} + 0.35P^{ren}$$

$$2000 = 0.50P^{ren} + 0.45P^{ren} + 0.35P^{ren}$$

$$2000 = 1.3(P^{ren})$$

Therefore,

$$P^{ren} = 1538.5MW = P_X^{ren} = P_Y^{ren} = P_Z^{ren}$$

ii. Renewable energy served is based on the percentage of the total renewable energy potential.

$$P^{ren}(\max) = P_X^{ren}(\max) + P_Y^{ren}(\max) + P_Z^{ren}(\max)$$

$$P^{ren}(\max) = 10000 + 40000 + 30000 = 80000MW$$

$$P_X^{ren} = \frac{10000}{80000} P^{ren} = 0.125 P^{ren} \tag{8}$$

$$P_Y^{ren} = \frac{10000}{80000} P^{ren} = 0.50 P^{ren} \tag{9}$$

$$P_Z^{ren} = \frac{30000}{80000} P^{ren} = 0.375 P^{ren} \tag{10}$$

From Equation (6)

$$2000 = 0.50 P_X^{ren} + 0.45 P_Y^{ren} + 0.35 P_Z^{ren}$$

Equations (8-10) are now substituted into equation (6)

$$2000 = 0.50(0.125) P^{ren} + 0.45(0.50) P^{ren} + 0.35(0.375) P^{ren}$$

$$2000 = 0.50(0.125) P^{ren} + 0.45(0.50) P^{ren} + 0.35(0.375) P^{ren}$$

$$2000 = .41875 P^{ren}$$

Therefore,

$$P^{ren} = 4776\, MW$$

$$P_X^{ren} = 0.125 P^{ren} = 597\, MW$$

$$P_Y^{ren} = 0.50 P^{ren} = 2388\, MW$$

$$P_Z^{ren} = 0.375 P^{ren} = 1791 MW$$