Understanding the cost of insurance against blackouts

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Links available at https://github.com/badber/EEE_PowerSystems

1. To be secure against a blackout, enough inertia and frequency response must be available, following this rule (if you are interested, you can check this paper for more info):

$$H \cdot R \geq \frac{(P_\mathrm{L})^2 \cdot f_0 \cdot \mathrm{T_d}}{4 \cdot \Delta f_\mathrm{max}} \tag{1}$$

   How much does it cost to cover the $N-1$ reliability requirement? How much does it cost to cover the $N-2$ reliability requirement?

2. Battery storage systems can provide frequency response much faster than thermal generators, therefore providing a service called Enhanced Frequency Response (EFR) in the UK. EFR reduces the need for regular frequency response, following this rule (if you are interested, you can check this paper for more info):

$$\left(\frac{H}{f_0} - \mathrm{EFR} \cdot \frac{\mathrm{T_{EFR}}}{4 \cdot \Delta f_\mathrm{max}}\right) \cdot R \geq \frac{(P_\mathrm{L} - \mathrm{EFR})^2 \cdot \mathrm{T_d}}{4 \cdot \Delta f_\mathrm{max}} \tag{2}$$

   Considering the $N-1$ reliability requirement, how much response can EFR replace, if we have 200MW of EFR in the system? In other words, how much less response is needed now that we have 200MW of EFR, compared to the case with no EFR in question 1?

3. We have demonstrated in our research that reducing the power output of large nuclear units in the UK can reduce overall carbon emissions (if you are interested, you can check this paper for more info).

   Given that nuclear units are zero-carbon generators, what do you think is the reason behind this reduction in emissions?

   Hint: think of who are the main providers of inertia and frequency response.

Nomenclature

H: system level of inertia (Units: $\mathrm{MW} \cdot \mathrm{s}$).
R: amount of frequency response scheduled (Units: MW).
EFR: amount of EFR scheduled (Units: MW).
P_L: value of the generation outage we want to secure against (Units: MW).
f_0: nominal electric frequency of the power grid (Units: Hz).
Δf_max: maximum admissible frequency deviation to avoid load shedding (Units: Hz).
$\mathrm{T_d}$: Delivery-time of frequency response (Units: s).
$\mathrm{T_{EFR}}$: Delivery-time of EFR (Units: s).

Data for solving the problems

– Assume a system level of inertia of 150GWs, i.e. $H = 100$GWs.
– Cost of frequency response: £5/MW.
– Largest generation unit in the UK: 1.8GW, from nuclear station Hinkley Point C.
– Second-largest generation unit in the UK: 1.25GW, from nuclear station Heysham 2.
– Other numerical values: $f_0 = 50$Hz, $\Delta f_\mathrm{max} = 0.8$Hz, $\mathrm{T_d} = 10$s, $\mathrm{T_{EFR}} = 0.5$s.

Answers

- Question 1:

  Cost for the $N-1$ reliability requirement: £16.88k

  Cost for the $N-2$ reliability requirement: £48.45k

- Question 2: 200MW of EFR can replace 680MW of response in this case.

- Question 3:

  We can distinguish two different operating conditions for a low-carbon power system:

  1. When renewable generation is low, we need thermal generators online to cover the demand. These thermal generators provide inertia, and we can part-load a few of them to provide some response without significantly increasing the operating cost of the system. In these conditions, it is optimal to fully-load large nuclear units: they provide cheap energy while not contributing to carbon emissions
  2. When renewable generation is high, we may even be able to cover all of the demand with renewables. However, we will still need to bring online some thermal generators simply for providing inertia and response. If we part-load large nuclear units, we can effectively reduce the size of the N-1 reliability requirement, therefore less thermal units are needed to provide frequency services, and in turn more renewables can be accommodated. This approach can reduce both the operating cost of the system (since renewables have zero marginal cost) and reduce carbon emissions.