System planning, EG2050 Probabilistic production cost simulation of electricity markets – lecture 14

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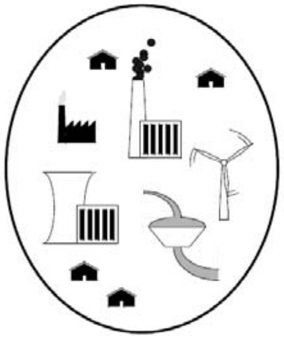
PPC model



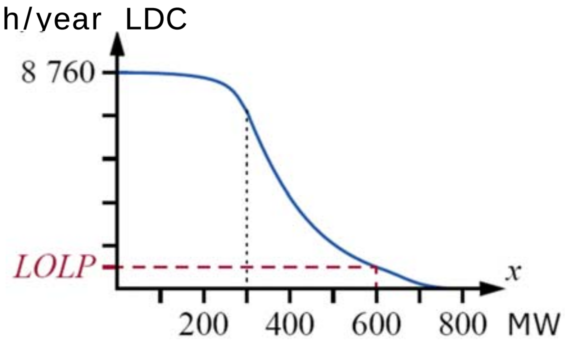
Assume

- Perfect competition
- Perfect information
- Load is not price sensitive
- Neglect grid losses and limitations
- All scenario parameters can be treated as independent

Some of these assumption can be treated with some specific methods.

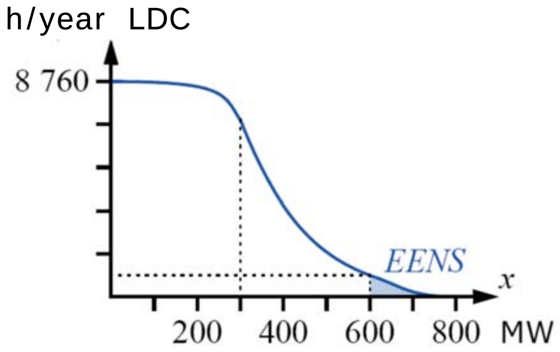
Calculation of system index - Basic idea

LOLP = LDC(600) = 876 h/year = 10%



Calculation of system index - Basic idea

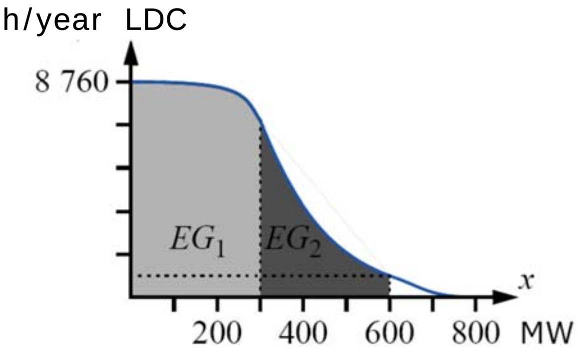
$$EENS = \int_{600}^{\infty} LDC(x)dx$$



Calculation of system index - Basic idea

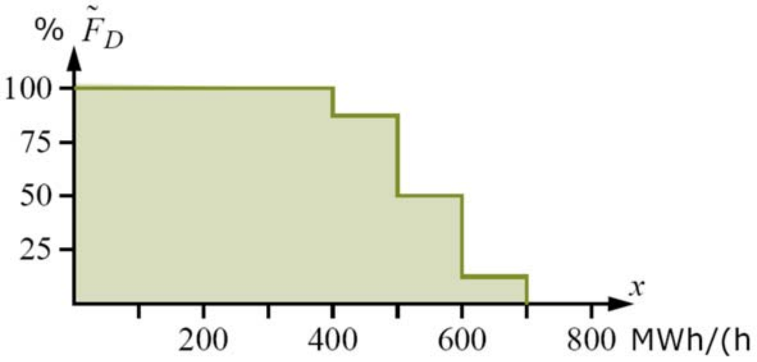
$$ETOC = \beta_1 EG_1 + \beta_2 EG_2$$

Perfect competition $\Rightarrow$ Unit 1 is used first, since $ß_1 \leq ß_2$



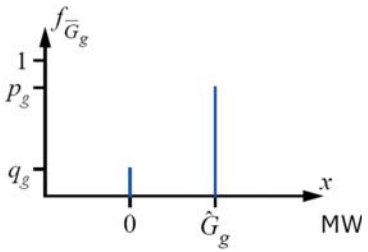
Load model – Alternative 2

Example 6.8:



The area is now changed since the y-axes is divided with T. To get the correct expected value, the area has to be multiplied with T.

Thermal power station model



- The availability of a thermal power station can not be calculated, but has to be estimated from historical data and forecasts of the future.

Equivalent load

Definition 6.10. The equivalent load is given by

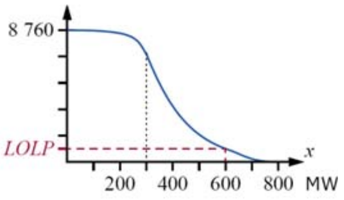
$$E_g = D + \sum_{k=1}^{g} O_k,$$

where

E_g = equivalent load for the power plant next to be dispatched after unit g,
D = actual load,
O_k = outage in unit k.

Calculation of system indeces

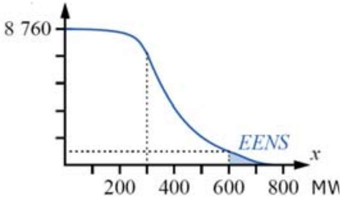
- Risk of capacity deficit = Loss of load probability. Capacity deficit occurs when the deman exceeds available production capacity, i.e.



$$\begin{aligned} LOLP_g &= P(D > \overline{G}_g^{tot}) = P(D > \hat{G}_g^{tot} - O_g^{tot}) \\ &= P(D + O_g^{tot} > \hat{G}_g^{tot}) = P(E_g > \hat{G}_g^{tot}) \\ &= \tilde{F}_g(\hat{G}_g^{tot}). \end{aligned}$$

Calculation of system indeces

- Expected Energy Not Served, EENS: This means energy that cannot be delivered depending on capacity deficit, i.e., equivalent load > installed capacity



$$EENS_g = T \int_{\hat{G}_g^{tot}}^{\infty} \tilde{F}_g(x)dx.$$

Calculation of system indeces

- Expected energy production in power plants, EG: Assume that we do not have unit g. Then the expected unserved energy is $EENS_{g-1}$. When unit g is then installed the expected unserved energy decreases to $EENS_g$. The difference is expected energy production in the unit.

$$EG_g = EENS_{g-1} - EENS_g.$$

Calculation of system indeces

- ***Example 6.4.*** Study the same system as in example 6.3. What does the equivalent load duration curve look like?
- The definition of the equivalent load is:

$$E_g = D + \sum_{k=1}^{g} O_k,$$

- This means convolution since the equivalent load is a sum of independent stochastic variables

Calculation of equivalent load load duration curve, ELDC

- General formula:

$$\tilde{F}_g(x) = p_g \cdot \tilde{F}_{g-1}(x) + q_g \cdot \tilde{F}_{g-1}(x - \hat{G}_g).$$

- Assume an LDC and one power plant with availability $p_1 \Rightarrow$ ELDC:

$$\tilde{F}_1(x) = p_1 \cdot \tilde{F}_0(x) + q_1 \cdot \tilde{F}_0(x - \hat{G}_1).$$

- The equivalent load is > x, when
  - unit available, load is > x, probability p_1
  - outage of G_1, load > x-G_1, probability q_1

Model of a wind power station

The production varies when the wind varies

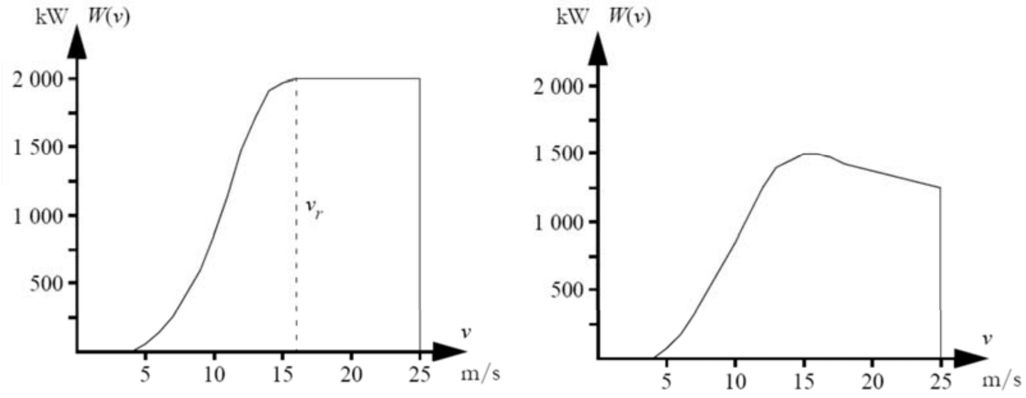


Figure 6.10 The relation between wind speed and electricity generation for two kinds of wind power plants (Vestas V80-2.0 MW and NEG Micon NM 1500C).

Model of a wind power station

The wind varies

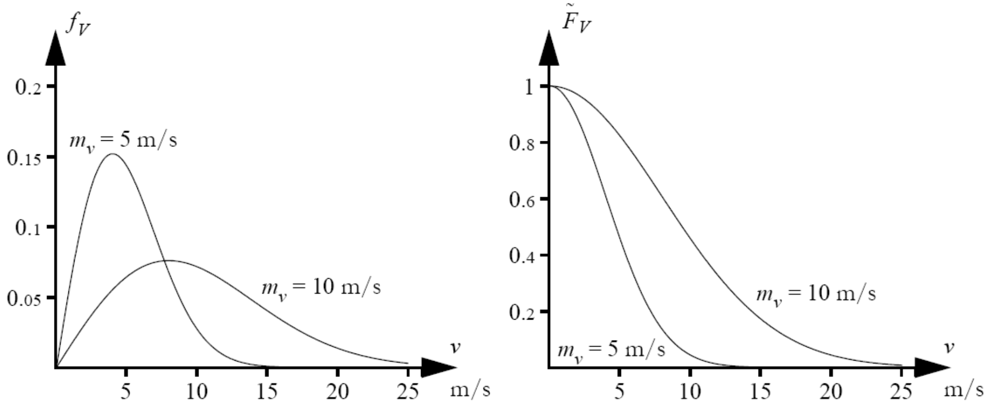


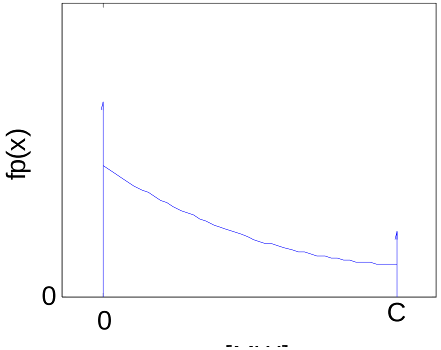
Figure 6.11 The density function and duration curves of Rayleigh distributed wind speeds.

Model of a wind turbine

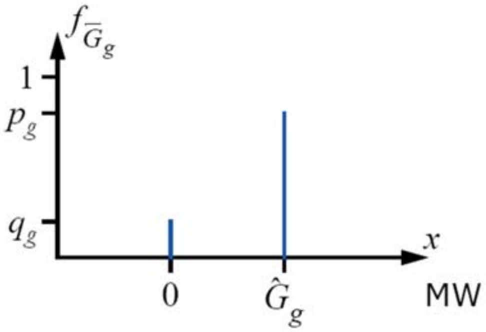
- There is one discrete probability that the wind power plant will not produce anything, i.e. When there is too little wind, too much wind or there is an outage.
- There is one discrete probability that the wind power plant will produce installed capacity, i.e. When the wind is higher than rated wind speed and lower than cut-off wind speed, and there is no outage.
- During the rest of the time there is a continous distribution between 0 MW and installed capacity

Model of a wind turbine

Wind power probability function



Thermal power probability function



Model of many wind turbines

- The production in several wind power plants can not be treated as independent variables, since high wind in one place normally means high winds in neighbouring regions

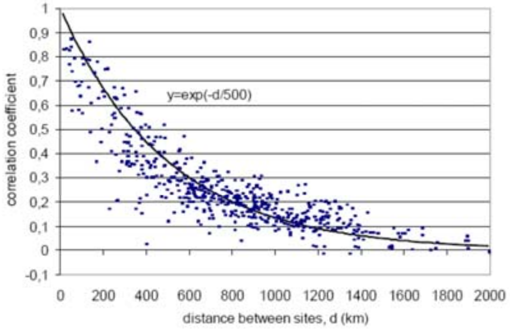
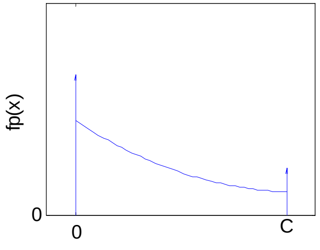


Figure 10. Cross correlation coefficients for the sites in the Nordic data for year 2001.

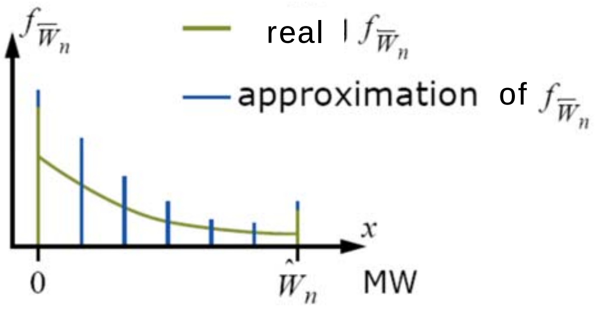
Model of many wind turbines

- Since PPC is based on independence between unit variation (outages) in different power plants, all wind power has to be treated as one source:
- Compared to one unit pdf, the discrete probabilities are much smaller



Model of wind power

- Available wind power capacity is a continous stochastic variable ⇒ use discrete approximation.



Model of wind power

- Thermal power is treated with two states: Installed capacity or zero.
- Total wind power is treated with a multi-state unit:
- ELDC Convolution with thermal power:

$$\tilde{F}_g(x) = p_g \cdot \tilde{F}_{g-1}(x) + q_g \cdot \tilde{F}_{g-1}(x - \hat{G}_g).$$

- Wind power: $\tilde{F}_g(x) = \sum_{i=1}^{N_g} p_{g,i} \tilde{F}_{g-1}(x - x_{g,i}),$

N_g = number of states in power plant g,

$p_{g,i} = f_{W_g}(\overline{W} - x_{g,i})$ = probability of state i,

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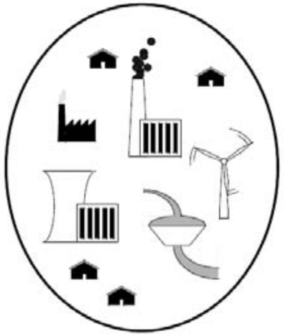
PPC model



Assume

- Perfect competition
- Perfect information
- Load is not price sensitive
- Neglect grid losses and limitations
- All scenario parameters can be treated as independent

Some of these assumption can be treated with some specific methods.

Wind power in PPC

- ”All scenario parameters can be treated as independent”
- Outages in thermal power plant can be considered to be independent on wind speed
- There is often a common variation between load and wind:

  time coupling: treat as independent in each period

  special couplings (e.g. low wind when it is extremely cold): treat as independent in each period

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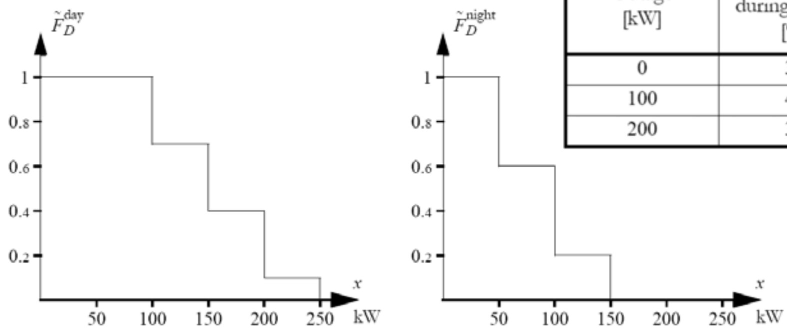
Wind power in PPC

- ***Example 6.13 (the power system in a small island):*** The small island Kobben is not connected to the national grid, but there is a local grid which is powered by a small wind power plant (installed capacity 200 kW) and a diesel generator set. The diesel generator set has a maximal capacity of 200 kW and the availability is 95%. A simplified model of the wind power plant is stated in table 6.5. The load duration curve is shown in figure 6.12. Calculate the risk of power deficit in this system.

Example 6.13

Table 6.5 Model of the wind power plant in example 6.13.

Outage [kW]	Probability during the day [%]	Probability during the night [%]
0	30	10
100	40	50
200	30	40



a) Day time (7 a.m. to 9 p.m.) **b)** Night time (9 p.m. to 7 a.m.).

Figure 6.12 The load for the small island in example 6.13.

Example 6.13

Solution: We start by calculating the system *LOLP* during day time. The total installed capacity is 400 kW; hence, we get

$$LOLP^{\text{day}} = \tilde{F}_2^{\text{day}}(400) = 0.95\tilde{F}_1^{\text{day}}(400) + 0.05\tilde{F}_1^{\text{day}}(400-200) =$$

$$= 0.95 \cdot (0.3\tilde{F}_D^{\text{day}}(400-0) + 0.4\tilde{F}_D^{\text{day}}(400-100) + 0.3\tilde{F}_D^{\text{day}}(400-200)) +$$

$$+ 0.05 \cdot (0.3\tilde{F}_D^{\text{day}}(200-0) + 0.4\tilde{F}_D^{\text{day}}(200-100) + 0.3\tilde{F}_D^{\text{day}}(200-200)) =$$

$$= 0.95 \cdot (0.3 \cdot 0 + 0.4 \cdot 0 + 0.3 \cdot 0.1) + 0.05 \cdot (0.3 \cdot 0.1 + 0.4 \cdot 0.7 + 0.3 \cdot 1) = 5.9\%.$$

In the same way we can calculate the night time *LOLP*:

$$LOLP^{\text{night}} = 0.95 \cdot (0.1 \cdot 0 + 0.5 \cdot 0 + 0.4 \cdot 0) +$$
$$+ 0.05 \cdot (0.1 \cdot 0 + 0.5 \cdot 0.2 + 0.4 \cdot 1) = 2.5\%.$$

To calculate the total system *LOLP* we use the weighted average of these two values:

$$LOLP = \frac{14}{24} LOLP^{\text{day}} + \frac{10}{24} LOLP^{\text{night}} \approx 4.5\%.$$

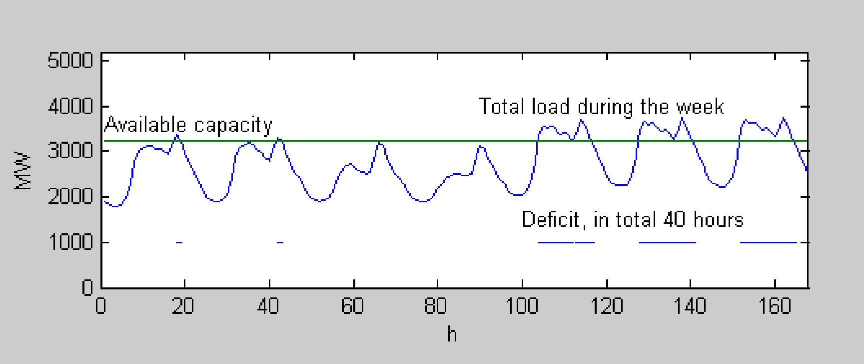
Power market simulations
- Capacity credit of a plant

- **Definition:** Capacity credit means the possibility of a power plant to increase the reliability (decrease in LOLP) of a plant
- **Question:** Is there any capacity credit for wind power?

Wind Power Capacity Credit
(expressed as equivalent load increase)

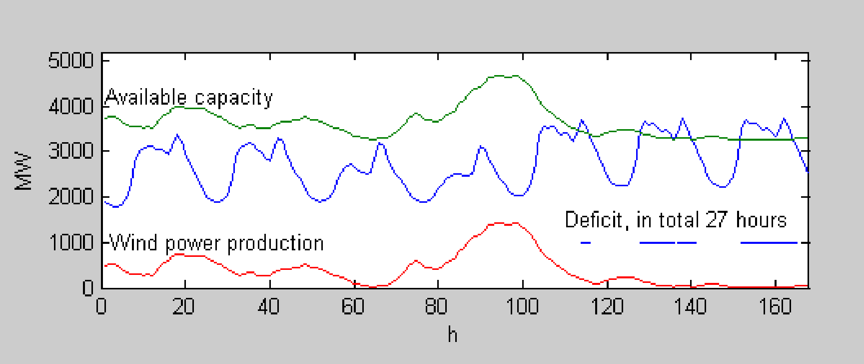
How much can the consumption increase when the amount of wind power increases and the risk of power deficit is kept constant?

Wind power capacity credit - 1



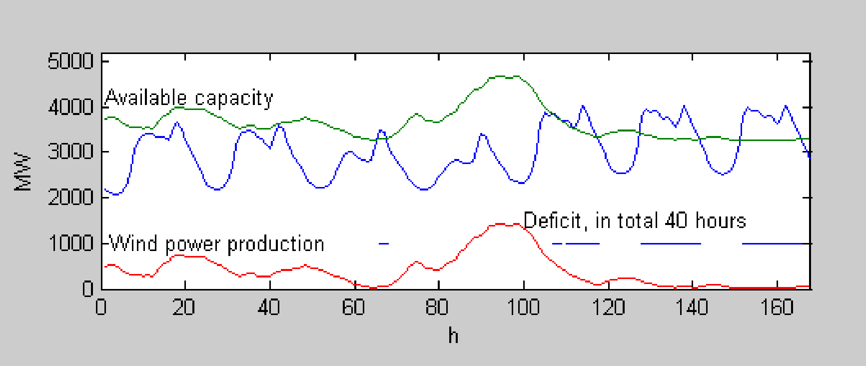
No wind power

Wind power capacity credit - 2



With wind power

Wind power capacity credit - 3



With wind power, load + 300 MW

Capacity credit of wind power

- **”True” value**: Considers the possibility of wind power increase the reliability of the power system, ≈ 20% of installed capacity.
- **Market value**: High market prices when there is a risk for power deficit.

Home assignments part IV

Simulation of an Electricity Market

In this assignment you will study a small electricity market. The small island republic Land consists of two main islands: Storön and Lillön. The two islands are connected by an HVDC transmission line. At present time the power supply in Land is based on a hydro power plant and an oil-fired condensing plant. The hydro power plant is a so-called run-of-the-river plant, i.e., there is no hydro reservoir. However, the natural water flow passing the hydro power plant is always sufficient to generate the installed capacity. Moreover, the southern coast of Lillön is quite windy; therefore, a large scale development of wind power is considered in this area.

Problem 17 (2 lab points)

Assume that the total load duration curve of Land can be approximated according to

$$\tilde{F}_0(x) = \begin{cases} 1 & x < 300, \\ 0.9 & 300 \le x < 400, \\ 0.5 & 400 \le x < 500, \\ 0.1 & 500 \le x < 600, \\ 0 & 600 \le x. \end{cases}$$

Use probabilistic production cost simulation to compute *ETOC* and *LOLP* if the electricity supply of Land consists of existing hydro power and oil condensing. Data of the power plants are given in table 8.

Problem 18 (3 lab points)

Consider the same system as in problem 17, but assume that the wind farm on Lillön is also built. Use probabilistic production cost simulation to compute *ETOC* and *LOLP*.

Table 8 Data for the power plants in Land.

Power source	Area	Installed capacity [MW]	Availability		Operation cost [¤/MWh]	Investment cost [M¤/yr.]
			Available capacity [MW]	Probability [%]		
Hydro power	Lillön	500	500	100	Negligible	Existing power plant
Oil condensing	Storön	300	0	10	150	Existing power plant
			300	90		
Wind power	Lillön	200	0	40	Negligible	25
			100	50		
			200	10		

Problem 19 (2 lab points)

Is the wind farm investment profitable for the power companies? Is the investment profitable for the society (i.e., include the social cost of disconnected load)?

*Problem 20 (1 bonus point)

The approximate load duration curve that you used in problem 17 and 18 is not very accurate. To obtain more precise results, the segment size of the load duration curve must be decreased (cf. the compendium page 101). You can download the Matlab function `ppc` from the course web pages. You can use this function to perform a probabilistic production cost simulation of the system. You supply data for the load and the power plants.[1] You can yourself set the segment size to be used when approximating the load duration curve. To get detailed instructions for calling the function in Matlab, type `help ppc` in the Matlab window. Notice that `ppc` uses a different approximative load duration curve compared to the one in problem 17 even if you use the same segment size as in problem 17.

Use `ppc` to simulate your system with at least five different segment sizes. How important is the segment size for the *ETOC* and the *LOLP*? Do the changes affect your conclusion about the profitability of investing in the wind farm?

Hint: You can also find the Matlab function `compareldc` on the course web pages. This function can be used to compare the exact load duration curve of a normally distributed load compared to a duration curve divided in segments.

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[1] Set the availability parameter `Wavail` to `[1 0 0]` in order to remove the wind power.