PROBABILISTIC SIMULATION

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Production Cost Analysis in WASP is performed using a Probabilistic Simulation

PURPOSE: To simulate the operation of electric power system units over a specified time period so that operating costs and reliability of system operation can be calculated.

PROBABILISTIC SIMULATION

- Calculates the expected value of energy generated by each generating unit in each time period.
- Calculates unit operating (production) costs on the basis of expected energy generation in each time period.
- Calculates system reliability parameters such as Loss-of-Load Probability (LOLP) and Energy-Not-Served (ENS).

Representation of Generating Unit Outages in Probabilistic Simulation

Two types of generating unit outages are modeled:

- **scheduled maintenance,** **expressed in terms of days of maintenance per year or scheduled maintenance rate**

- **forced outages,** **expressed in terms of forced outage rate (FOR)**

Methods of Accounting for Forced Outages in Probabilistic Simulation

Derating

Derated capacity = Nominal capacity * (1 - FOR)

Maintenance extension

Total unavailability rate = Scheduled outage rate + FOR

***Monte Carlo method*: random numbers rn $\in$ (0,1) are drawn for each unit and compared with the unit FOR:**

- **if rn $\leq$ FOR unit is assumed on forced outage**
- **if rn > FOR unit is assumed available for operation**

Baleriaux-Booth Method

BALERIAUX-BOOTH METHOD

- Technique addresses unit outage probabilities in combination with system load variations.
- The capacity outage due to forced outage is treated as additional load that must be served by other units.
- The resulting curve is called the equivalent load duration curve - ELDC.
- ELDC represents the original system load combined with the probabilistically determined forced outage capacities.

Baleriaux-booth Probabilistic Simulation Method in WASP

- Load Duration Curves (LDCs) used to represent system load
- Loading Order used to represent generating unit dispatch:
  - **Economic loading order (provided by CONGEN)**
  - **User-specified loading order**
- Probabilistic mathematics used to represent the random forced outages of generating units
- Above three are combined to represent the interaction of system load and outages of generating units in the form of equivalent load duration curves (ELDCs).

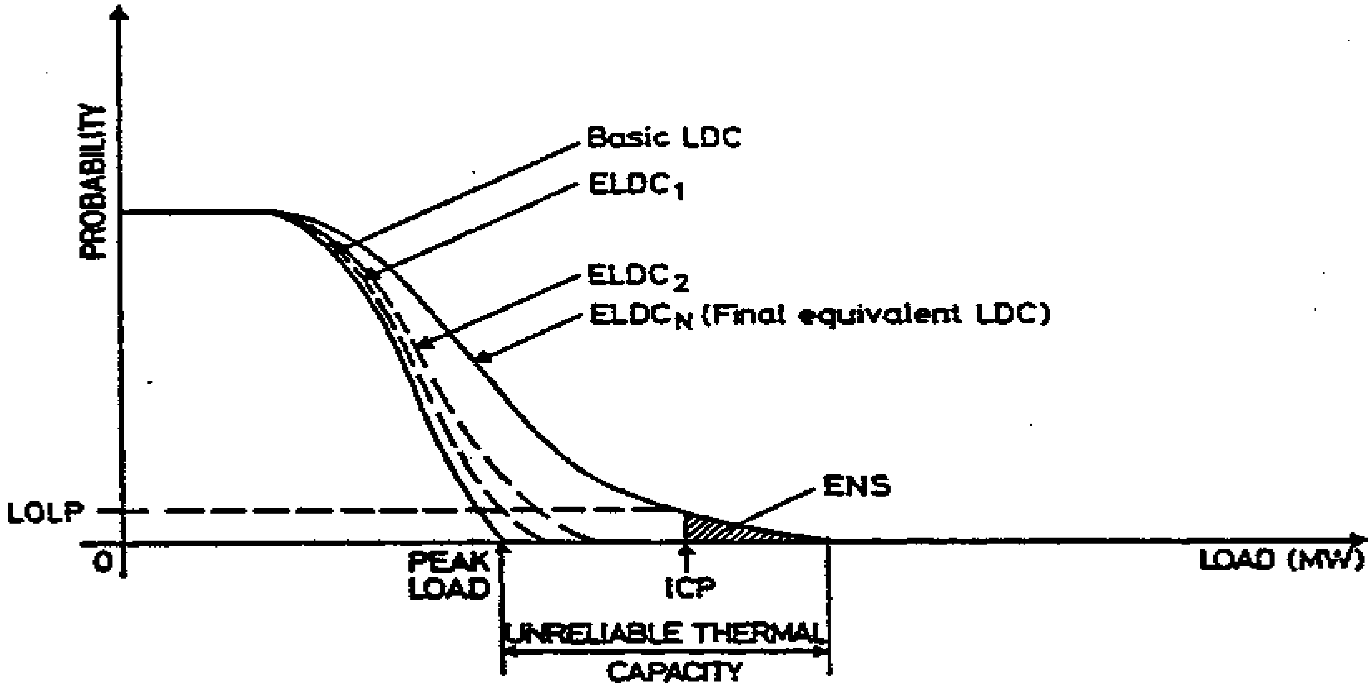
ELDC CONSTRUCTION

- A sequence of ELDCs is constructed by dispatching a generating unit under the ELDC to determine the unit's generation and then determining the effect of the unit forced outage rate on the ELDC.

- Each successive ELDC consists of a weighted average between the previous load curve and the same load curve displaced by the capacity of the unit being dispatched.

- The final ELDC is obtained after the convolution of all generating units is performed.

Equivalent Load Duration Curves; LOLP and ENS Calculation



ICP - Total generating capacity of the system
LOLP can be calculated by measuring the ordinate at load = ICP

$$ENS = T \cdot \int_{ICP}^{\infty} ELDC_N \, dx$$

where T is the length of the period (in hours) covered by the LDC.

CREATING INITIAL LOAD DURATION CURVE

Chronological (hour-by-hour) Loads

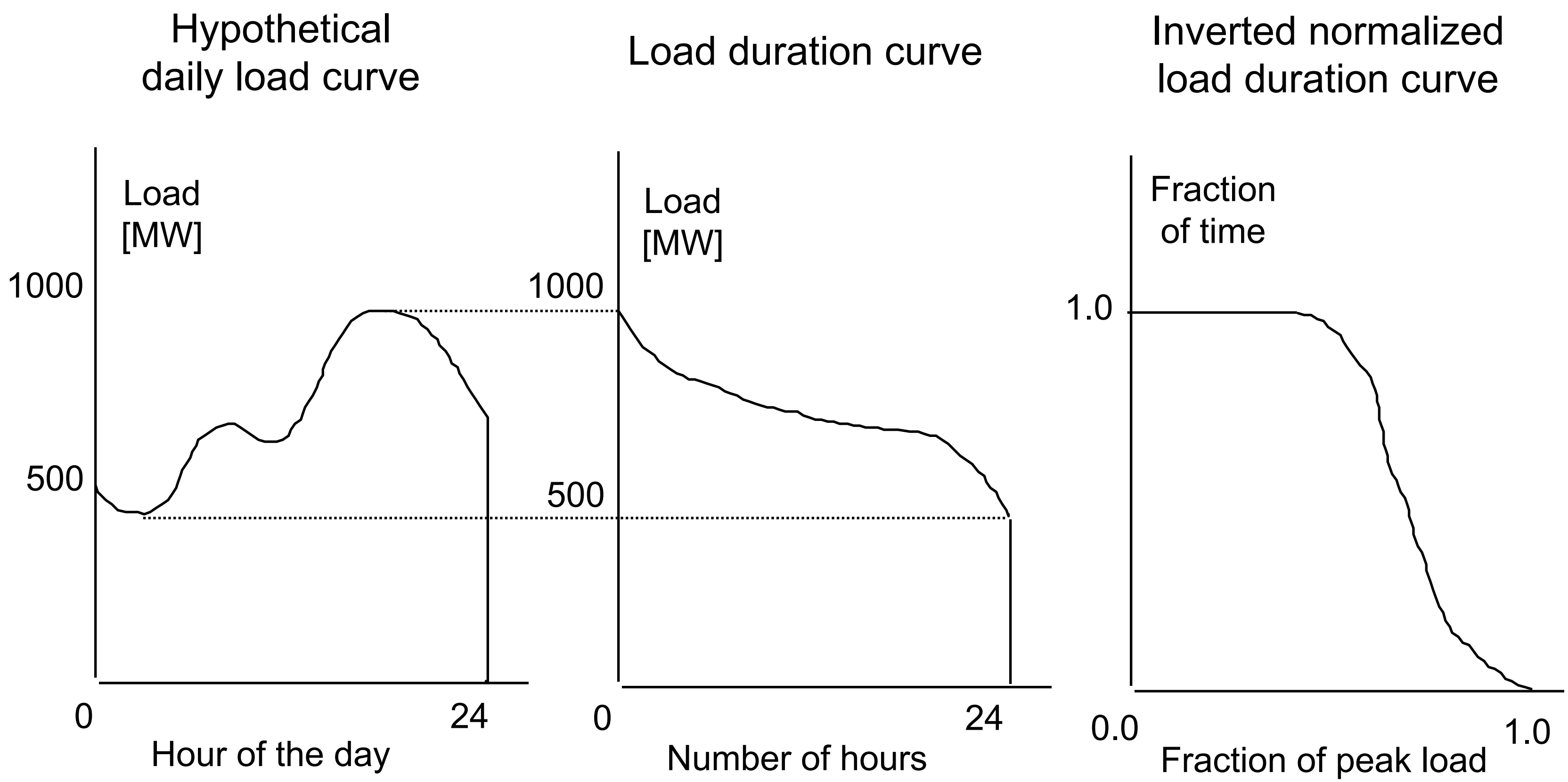
↓ **Rearrange Chronological Loads into Descending Order**

Load Duration Curve (normalized)

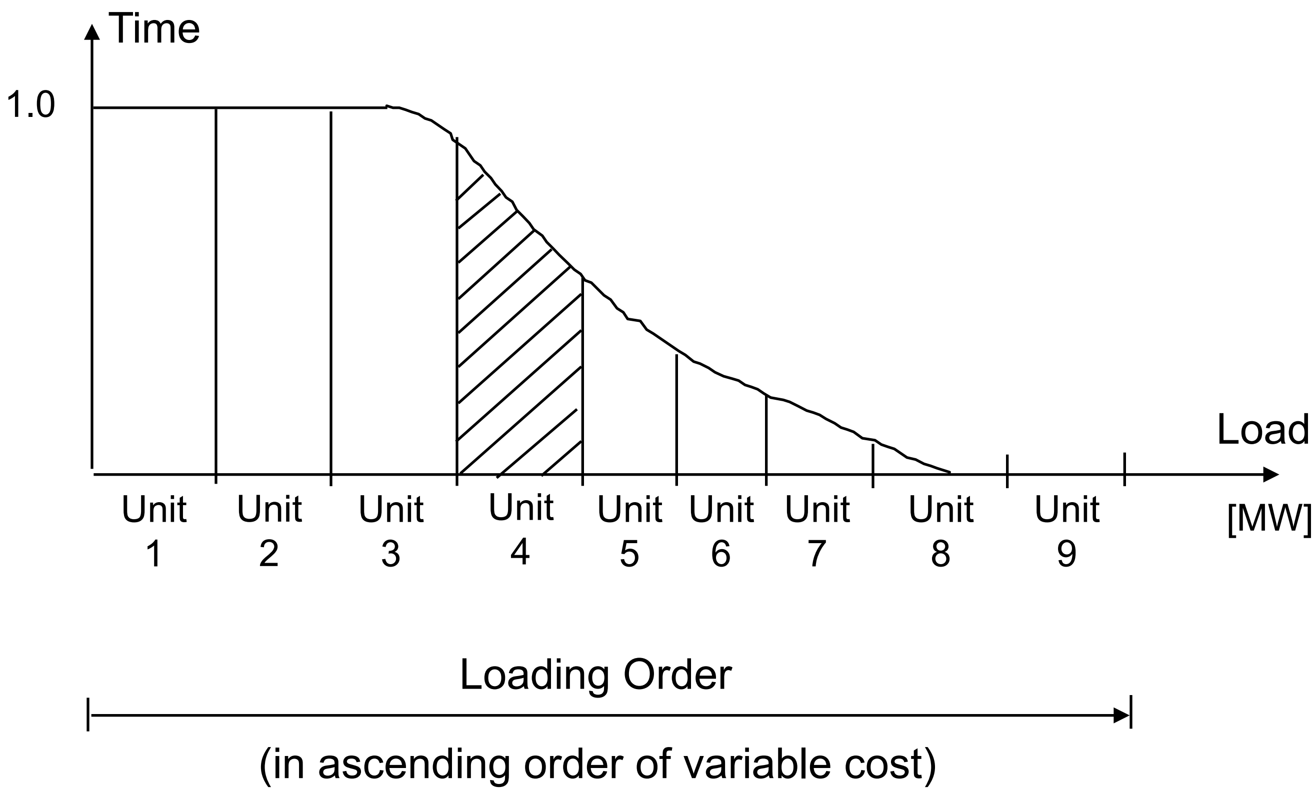
↓ **Interchange LDC's Ordinate and Abscissa**

Inverted Load Duration Curve

Inverted Normalized LDC



Units are Loaded under LDC to Determine Unit Generation



Forced Outages of Generating Units and Probability Mathematics

EXAMPLE: A system with two generating units:

Unit	Capacity	FOR
GEN1	100 MW	0.1
GEN2	200 MW	0.2

Calculation of the available capacity distribution:

Unit status		Total capacity [MW]		
GEN1	GEN2	Available	On outage	Probability
0	0	0	300	0.1 x 0.2 = 0.02
1	0	100	200	0.9 x 0.2 = 0.18
0	1	200	100	0.1 x 0.8 = 0.08
1	1	300	0	0.9 x 0.8 = 0.72
				1.00

General Convolution Equation

Points on the ELDC are calculated using the formula:

$$L_n(x) = p_n\, L_{n-1}(x) + q_n\, L_{n-1}(x-C_n)$$

where:

$L_n(x)$ = equivalent load duration curve (load probability function: probability that load is $\geq$ x) after considering the forced outages of the first n units

q_n = probability that unit n is on forced outage

p_n = probability that unit n is available for operation

$p_n + q_n = 1$

C_n = capacity of the n_{th} generating unit

2nd Example - Forced Outages of Generating Units and Probability Mathematics

EXAMPLE 2: A system with two generating units:

Unit	Capacity	FOR ("q")
GEN1	100 MW	0.5
GEN2	200 MW	0.4

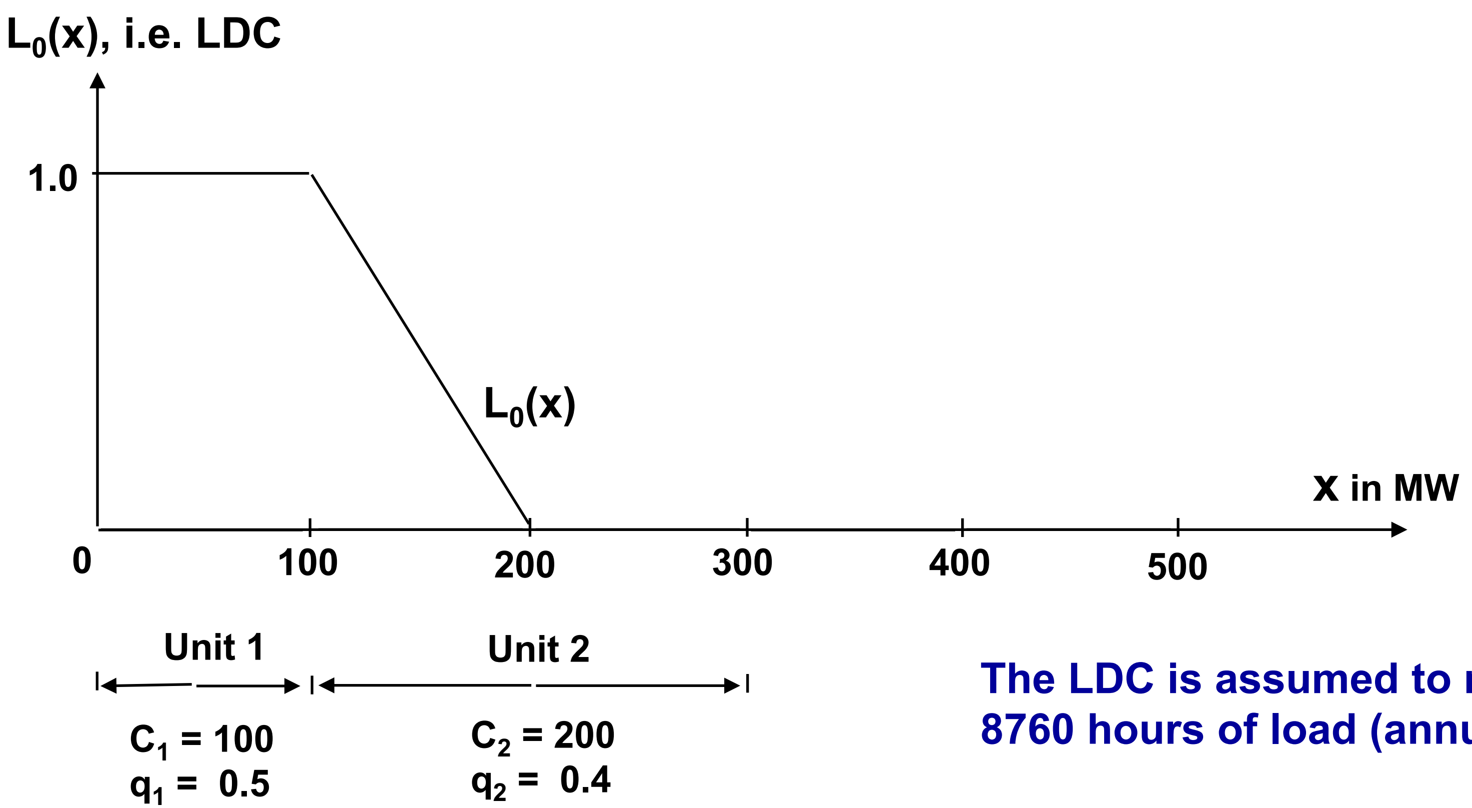
Calculation of the available capacity distribution:

Unit status		Total capacity [MW]		
GEN1	GEN2	Available	On outage	Probability
0	0	0	300	0.5 x 0.4 = 0.20
1	0	100	200	0.5 x 0.4 = 0.20
0	1	200	100	0.5 x 0.6 = 0.30
1	1	300	0	0.5 x 0.6 = 0.30
				1.00

Illustration of Equivalent Load

EXAMPLE: System of two generating units.

<u>Outage state</u>: Both units are available.



The LDC is assumed to represent 8760 hours of load (annual curve).

Illustration of Equivalent Load

<u>Outage state</u>: Unit 1 on forced outage
Unit 2 available

$L_0(x-100)$, i.e. LDC shifted by 100 MW to the right

Baleriaux-Booth method:

Instead of removing Unit 1 from the loading order and sliding Unit 2 to the left, leave the loading order unchanged and shift the LDC to the right by the capacity of Unit 1. The impact on Unit 2 is the same in either case.

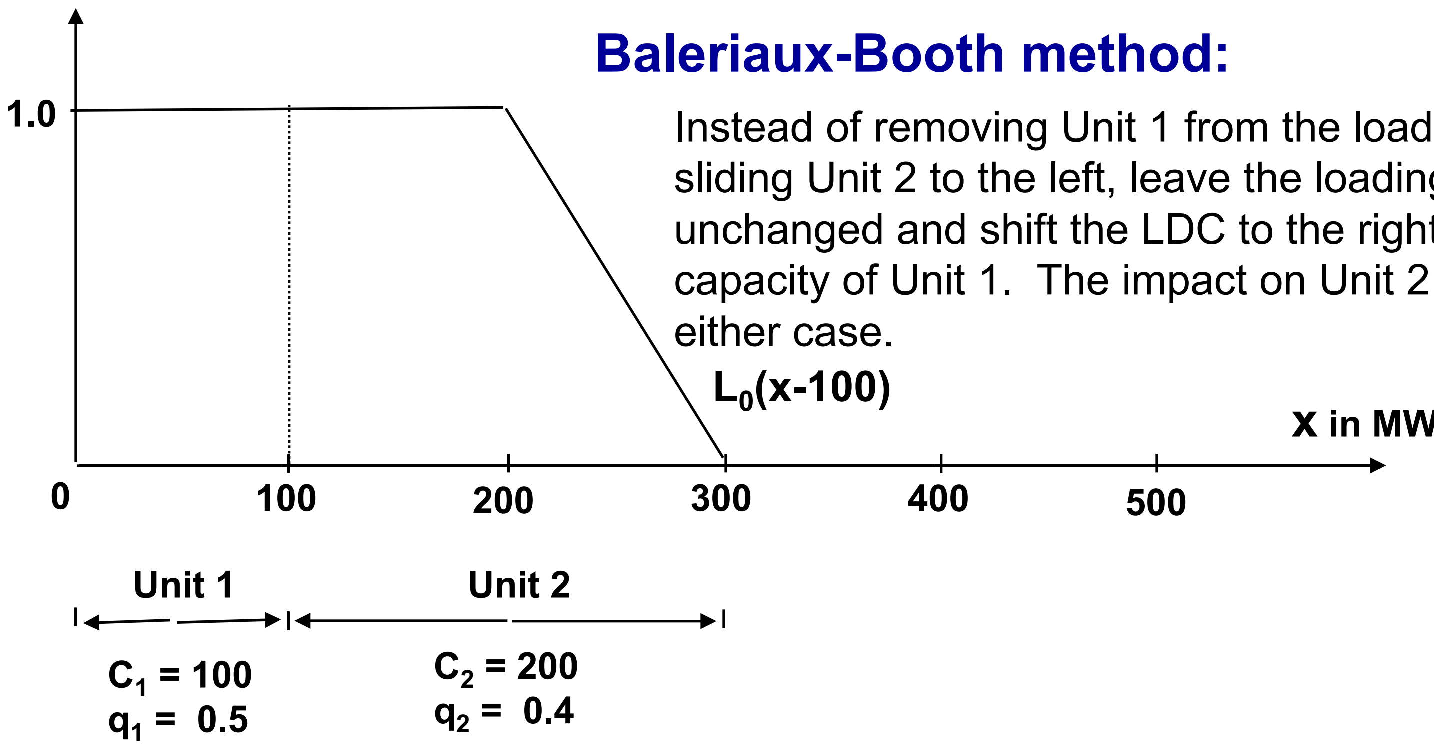
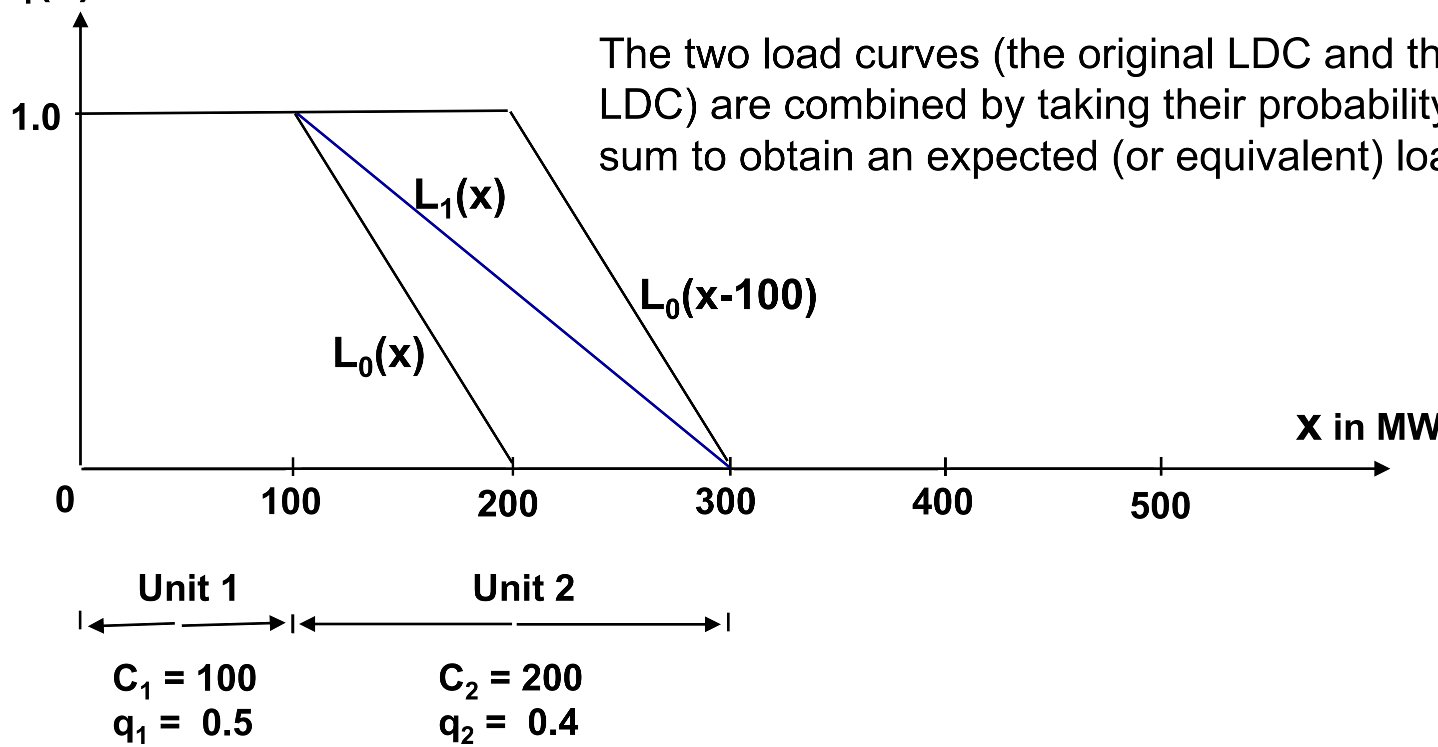


Illustration of Equivalent Load

Outage state: Unit 1 on forced outage
Unit 2 available

$L_1(x)$, i.e. LDC after the convolution of Unit 1

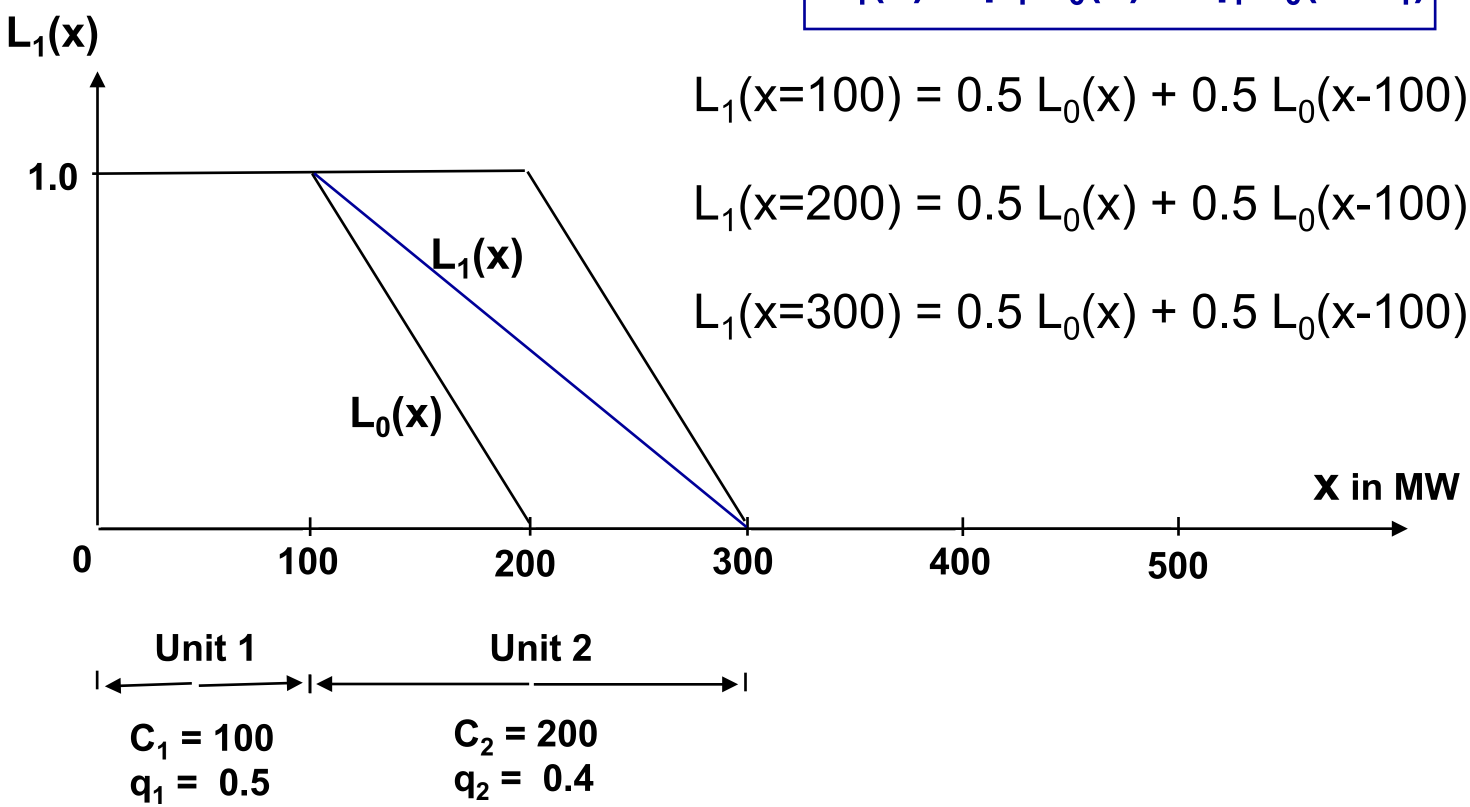


The two load curves (the original LDC and the shifted LDC) are combined by taking their probability-weighted sum to obtain an expected (or equivalent) load curve.

Convolution Process

Considering the effect of forced outages of Unit 1

$$L_1(x) = p_1 L_0(x) + q_1 L_0(x-C_1)$$



$L_1(x{=}100) = 0.5\ L_0(x) + 0.5\ L_0(x-100) = 1.0$

$L_1(x{=}200) = 0.5\ L_0(x) + 0.5\ L_0(x-100) = 0.5$

$L_1(x{=}300) = 0.5\ L_0(x) + 0.5\ L_0(x-100) = 0.0$

Convolution Process

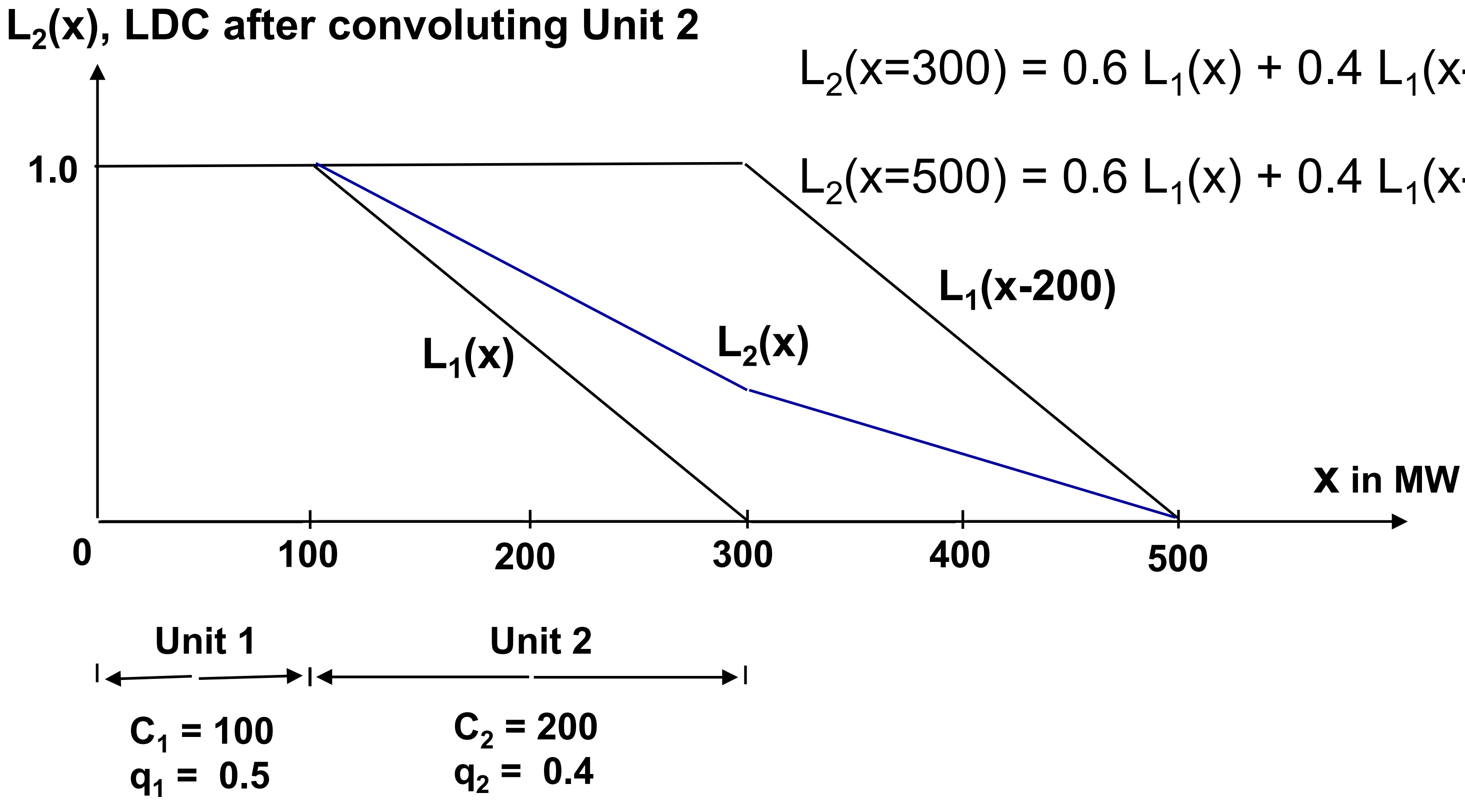
Considering the effect of forced outages of Unit 2

$$L_2(x) = p_2 L_1(x) + q_2 L_1(x-C_2)$$

$L_2(x=100) = 0.6\,L_1(x) + 0.4\,L_1(x\text{-}200) = 1.0$

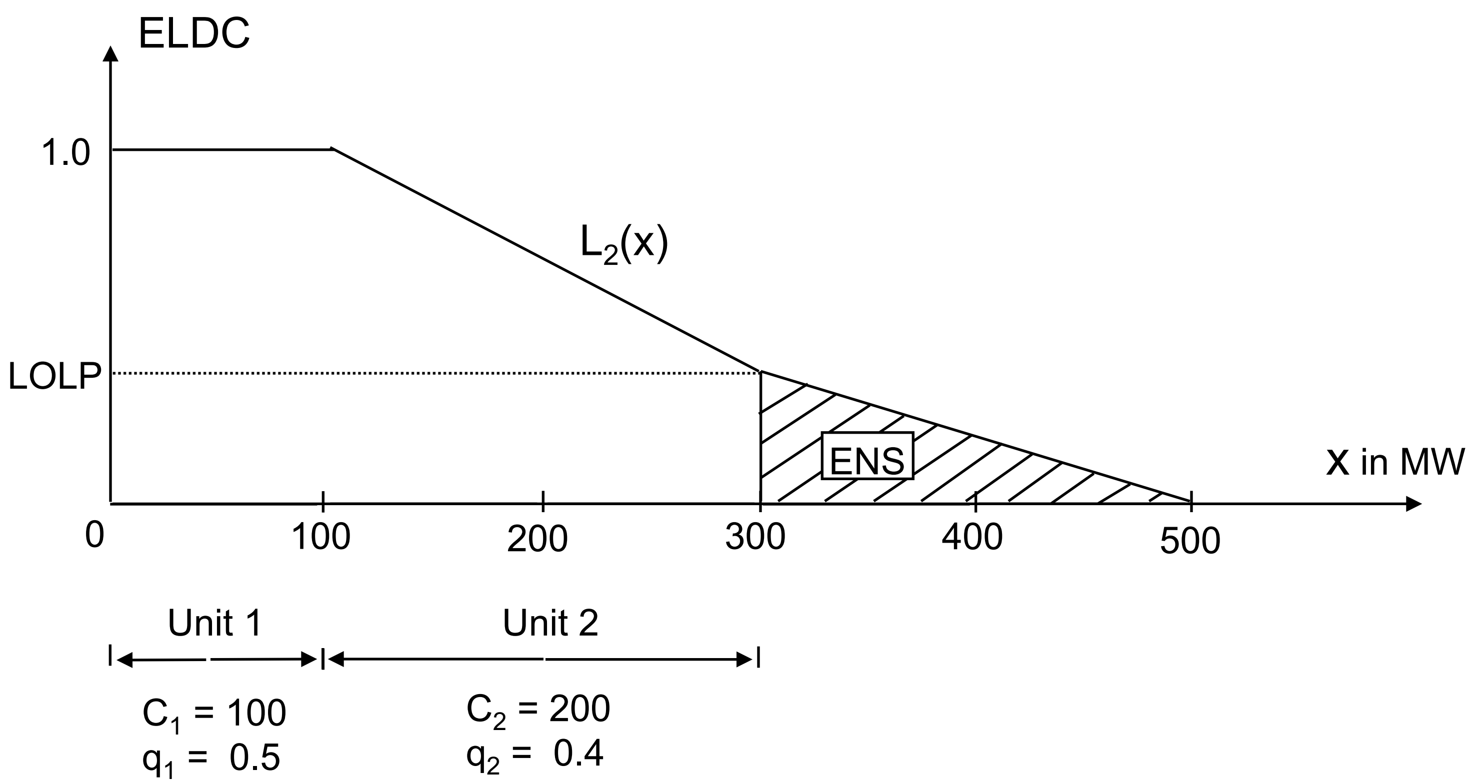
$L_2(x=300) = 0.6\,L_1(x) + 0.4\,L_1(x\text{-}200) = 0.4$

$L_2(x=500) = 0.6\,L_1(x) + 0.4\,L_1(x\text{-}200) = 0.0$



CALCULATION OF RELIABILITY PARAMETERS

LOLP and ENS



Thank you!

Any questions?