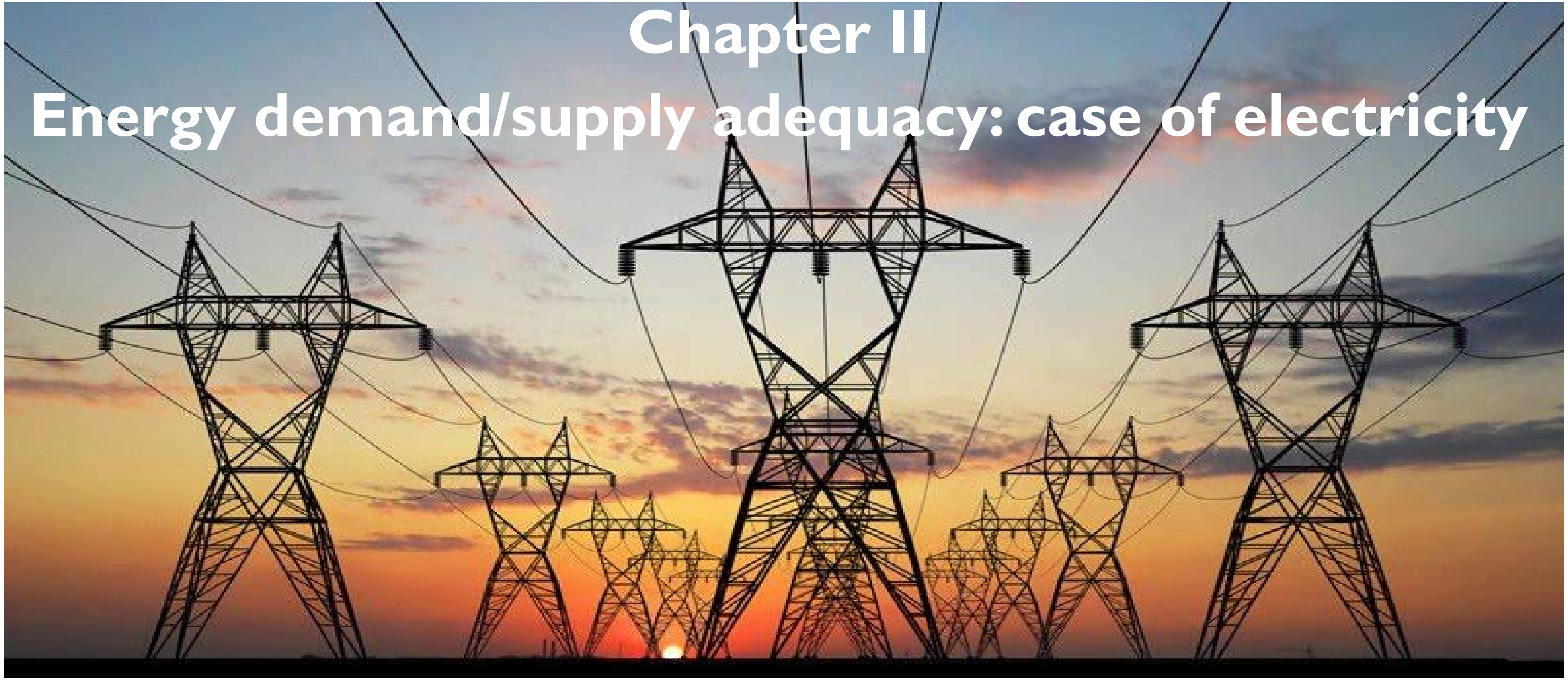
ENERGY PLANNING : MODELLING AND DECISION SUPPORT

Chapter II

Energy demand/supply adequacy: case of electricity



-CONTENT-

2.1 THE ISSUE OF ADEQUACY BETWEEN ENERGY DEMAND/SUPPLY

- Designing energy supplies in long term to meet economically the anticipated energy demand
- Verifying the quality of services: adequacy is only defined for a required quality of service
- Having different functions in energy supply depending on their respective characteristics i.e :base, intermediate and peaking plants
- Energy demand is uncertain; factors influencing the demand are weather conditions, seasonal and time of use fluctuations

- Energy supply is uncertain: factors influencing the supply are water inflows, limited storability and the capacity of the plants
- Modern adequacy paradigm includes both energy demand and supply planning in an integrated resource planning
- Energy demand planning: life cycle investments scheduled in order to master the energy demand
- Energy supply planning: life cycle investments scheduled in the generating systems in order to meet the anticipated demand with the required quality of service

2.2 PARTICULAR CASE OF ELECTRICITY

- Limited storability of electricity
- Management of the adequate shares of base, intermediate and peaking plants' capacities
- Management of the adequate reserve margin
- Particular difficulty in case of multiple generators and liberalized market

2.3 MODELING THE OPERATION OF THERMAL PLANTS

Availability concerns are related to the mechanical components of the plants

In some developing countries, fuels may be unavailable due to soaring energy prices

Efficiency, flexibility and availability factors influence the dispatching of the plants

Energy Efficiency

Efficiency

$$\eta = \frac{Electrical\ \ energy\ \ (output)}{Thermal\ \ Energy\ \ (input)}$$

$$= \frac{G}{H}$$

H: Hourly heat consumption when the electricity generation equals G [MWe]:H [kcal/h]

Average Fuel Consumption

$$C_s = \frac{H}{G}$$

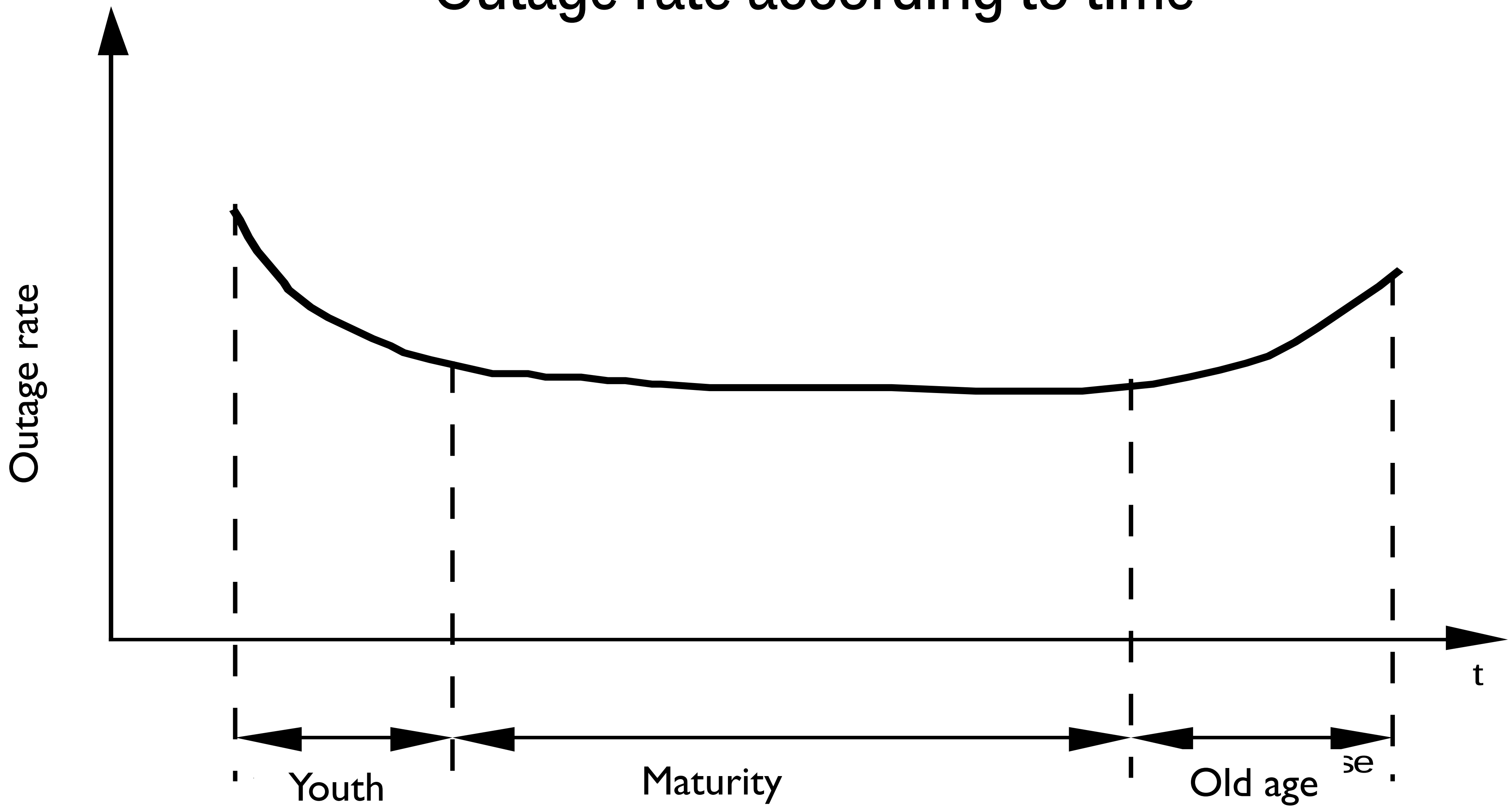
Incremental Heat Consumption

$$DC_s = \frac{dH}{dG}$$

H: Hourly heat consumption when the electricity generation equals G [MWe]:H [kcal/h]

Typical plants	Typical sized (Mwe)	Typical efficiency (%)
Conventional thermal Petroleum Fuel	200 - 800	32 - 40
Conventional fuel Coal	300 - 1200	30 - 38
Nuclear	500 - 1200	31 - 34
Gas turbine	50 - 100	22 - 28
Combined cycles Gas/heat	300 - 400	36 - 55
Diesel	10 - 30	27 - 30

Outage rate according to time



Availability

Load factor of the plant

$$FC = \frac{EP}{P_{\max} . DP}$$

Utilisation factor of the plant

$$FU = \frac{EP}{P_{inst} . DP}$$

EP : Net generation of electrical energy during the period DP [kWe]
P_{inst} : Installed capacity of the plant [kWe]
P_{max} : Maximum load of the plant during the period DP [kWe]
DP : Duration of the period in hours [h]

Availability

Complete outage rate

$$TPT = \frac{DPT}{DPT + DS}$$

Partial and complete outage rate

$$TPE = \frac{DPE}{DPE + DS}$$

$$DPE = \frac{1}{P_{max}} \sum_{i=1}^{N} PP_i . DP_i$$

TPT : Complete outage rate
TPE: Partial outage rate
DPT: Duration of complete outages [h]
DPE: Duration of partial and complete outages [h]

DP_i: Duration of outage i [h]
N: Total number of outages
P_{max}: Maximum power generated by the plant
PP_i: Reduction of the power generated by the plant due to the outage i

Availability

Outage rate for maintenance

$$TAPP = \frac{DAP}{DP}$$

$$TAPS = \frac{DAP}{DAP + DS}$$

TAPP : Maintenance outage rate with respect to the total period duration
TAPS : Maintenance outage rate with respect to the duration of the normal operation
DAP: Duration of the maintenance outage [h]
DS: Duration of the normal operation [h]
DP: Total duration of the period [h]

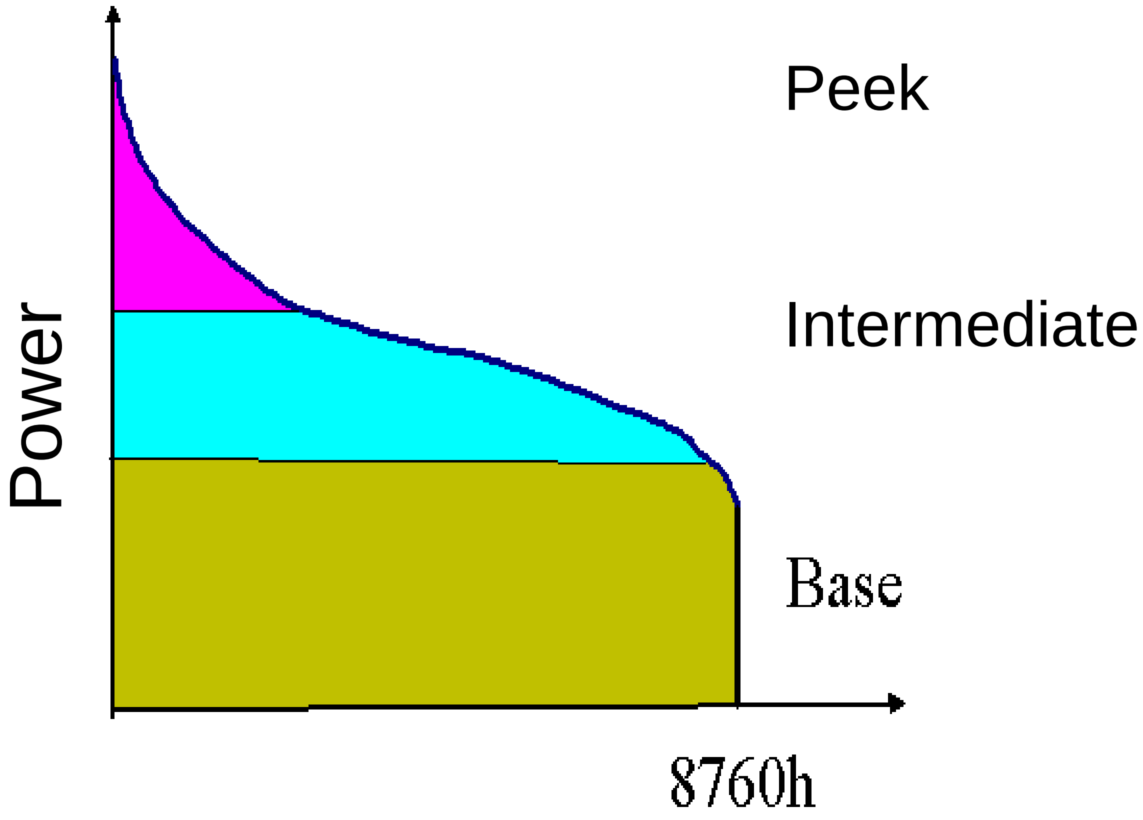
Flexibility of operation

- Time required for the start
- Contribution to the spinning
- Required time to attain the spinning reserve
- Maximum speed variation of the load

Flexibility of operation

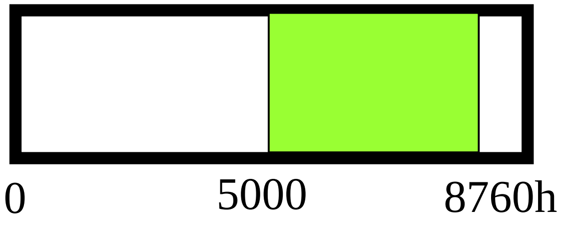
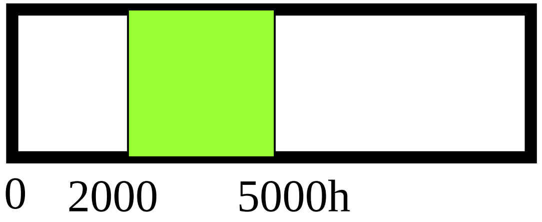
Plant type	Spinning reserve		Maximum speed	Start-up
	RT [%]	TR	VC	TG
Conventional steam plant	20	10 min	2 to 5% / min	Few hours
Nuclear plant	8 to 20	10 to 30 min	1.3 to 3% / min	Few hours
Gas turbine	100	5 s	20% / s	3 to 10 min

2.4 OPERATION OF A ELECTRICITY GENERATING SYSTEM : CASE OF HYDRO PLANTS



When and how long should each plant operate ?

Operation of an electricity generating system

Operation model	Typical plant	Maximum annual duration of operation
Operation to serve base loads	- Hydro. Run of river - Nuclear - Conventional steam	
Operation to serve intermediate loads	- Conventional steam - Combine cycle	
Operation to serve peak load	- Old conv. steam - Gas turbines - Hydro. with reservoirs - Pumped storage	

Operation of hydro plants

Regulated capacity

$$T_R = \frac{V_u}{P_M}$$

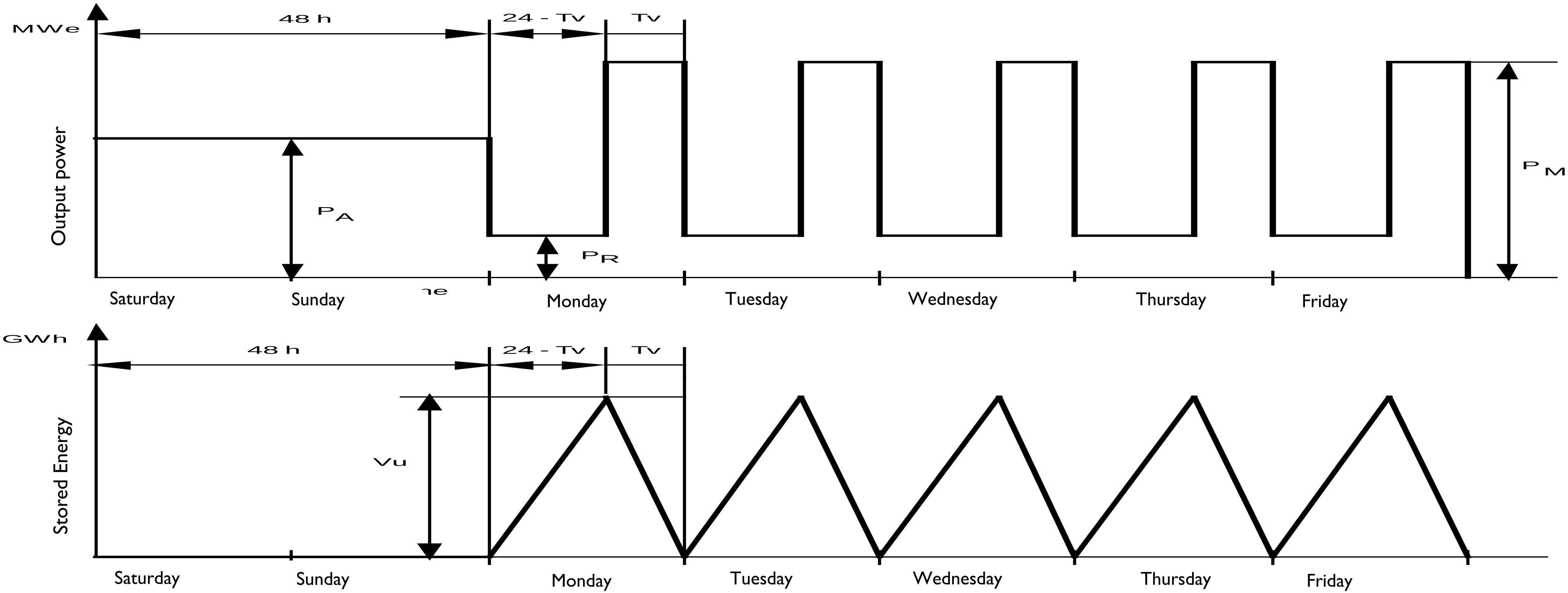
T_R : duration to empty at full power [h]

V_u: Useful volume of the reservoir [MWh]

P_M: Maximum power of the turbine [MWe]

Operation of hydro plants

Daily cycle mode



Operation of hydro plants

Daily cycle mode

Balance of the emptying phase

$$P_M T_V = V_u + P_A T_V$$

$$T_V (P_M - P_A) = V_u$$

$$T_V = \frac{V_u}{P_M - P_A}$$

Balance of the filling phase

$$V_u = (P_A - P_R)(24 - T_V)$$

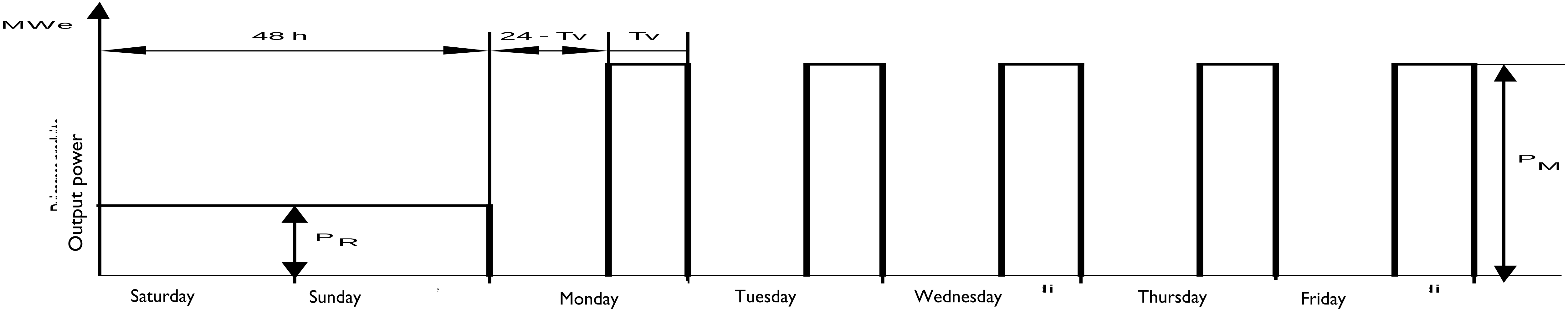
$$P_R = P_A - \frac{V_u}{24 - T_V} = P_A - \frac{V_u (P_M - P_A)}{24(P_M - P_A) - V_u}$$

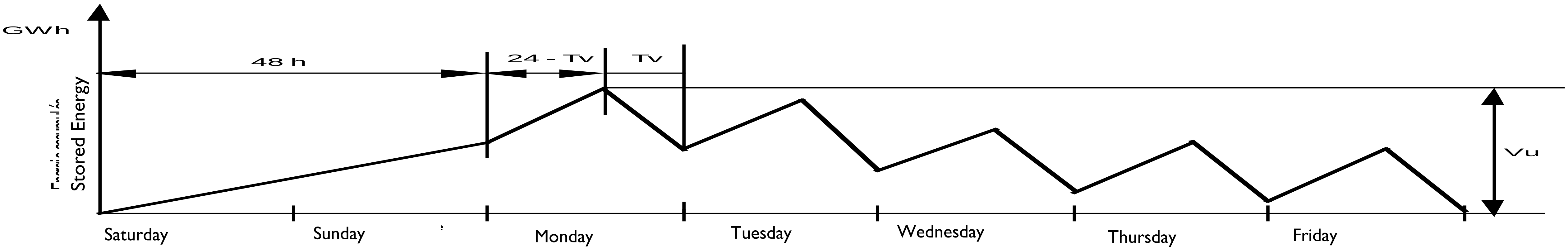
P_A : Average power of the hydro inflows [MWe]

P_R : Reduced power of the plant [MWe]

Operation of hydro plants

Weekly cycle mode





Operation of hydro plants

Weekly cycle mode

Balance of the emptying phase

$$5P_M T_V = V_u + 4.24.P_A + P_A T_V$$

$$T_V (5P_M - P_A) = V_u + 96 P_A$$

$$T_V = \frac{V_u + 96 P_A}{5P_M - P_A}$$

Balance of the filling phase

$$V_u = 48 (P_A - P_R) + (24 - T_V) P_A$$

$$P_R = \frac{1}{48}(48P_A + (24 - T_V) P_A - V_u)$$

Operation of hydro plants

General case

$$Max \left\{ B = \sum_{t=1}^{T} b_t(u_t) \right\}$$

$$\begin{cases} S_{t+1} = S_t + w_t - u_t - v_t \\ \underline{u}_t \leq u_t \leq \overline{u}_t \\ \underline{S}_t \leq S_t \leq \overline{S}_t \end{cases}$$

S_t: level of the reservoir at the beginning of season t

w_t : water inflow during the season t

u_t: amount of water that is turbined during the season t

v_t: amount of water that is spilled during the season t

2.5 DEMAND / SUPPLY ADEQUACY

case 1: the demand does not vary, however the supply varies

case 2: the demand varies, not the supply

case 3: both the demand and the supply vary

General case

- Adequacy criteria
- Probabilistic evaluation of adequacy

Adequacy Criteria and Evaluation

Deterministic criteria

- Reserve margin
- Criterion linked to the maximum unit size

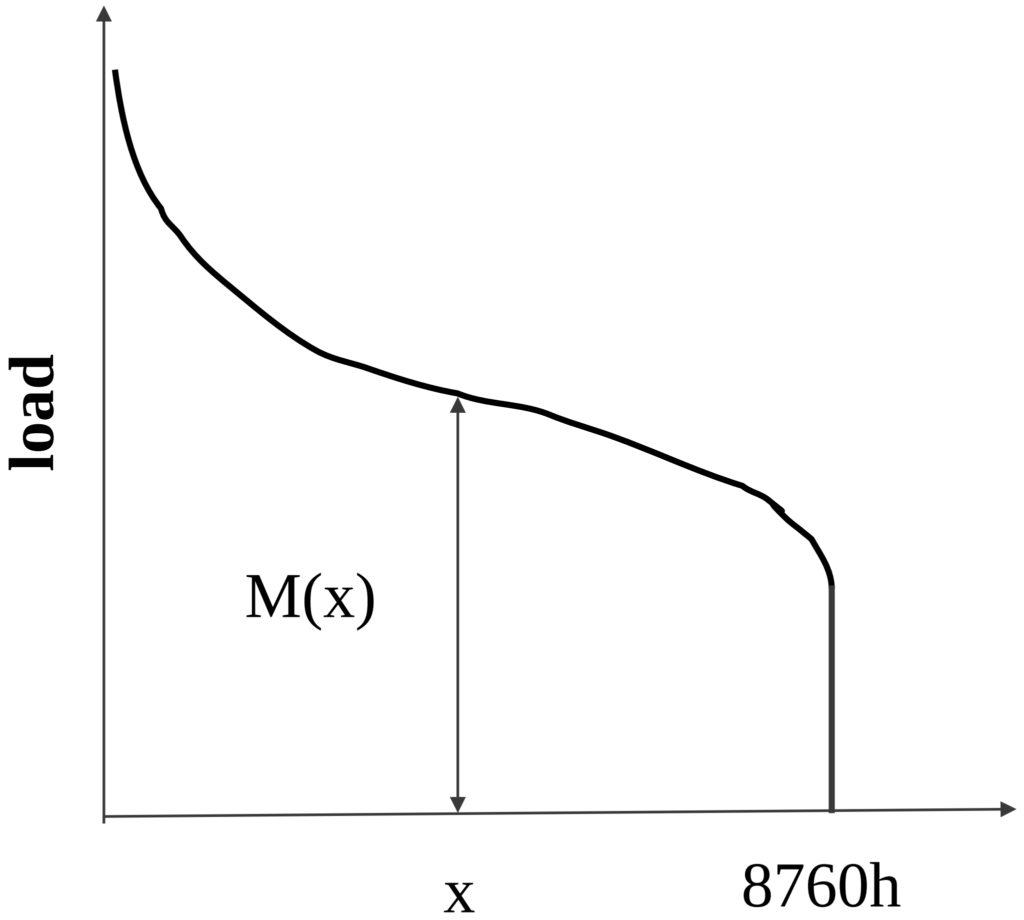
Probabilistic criteria

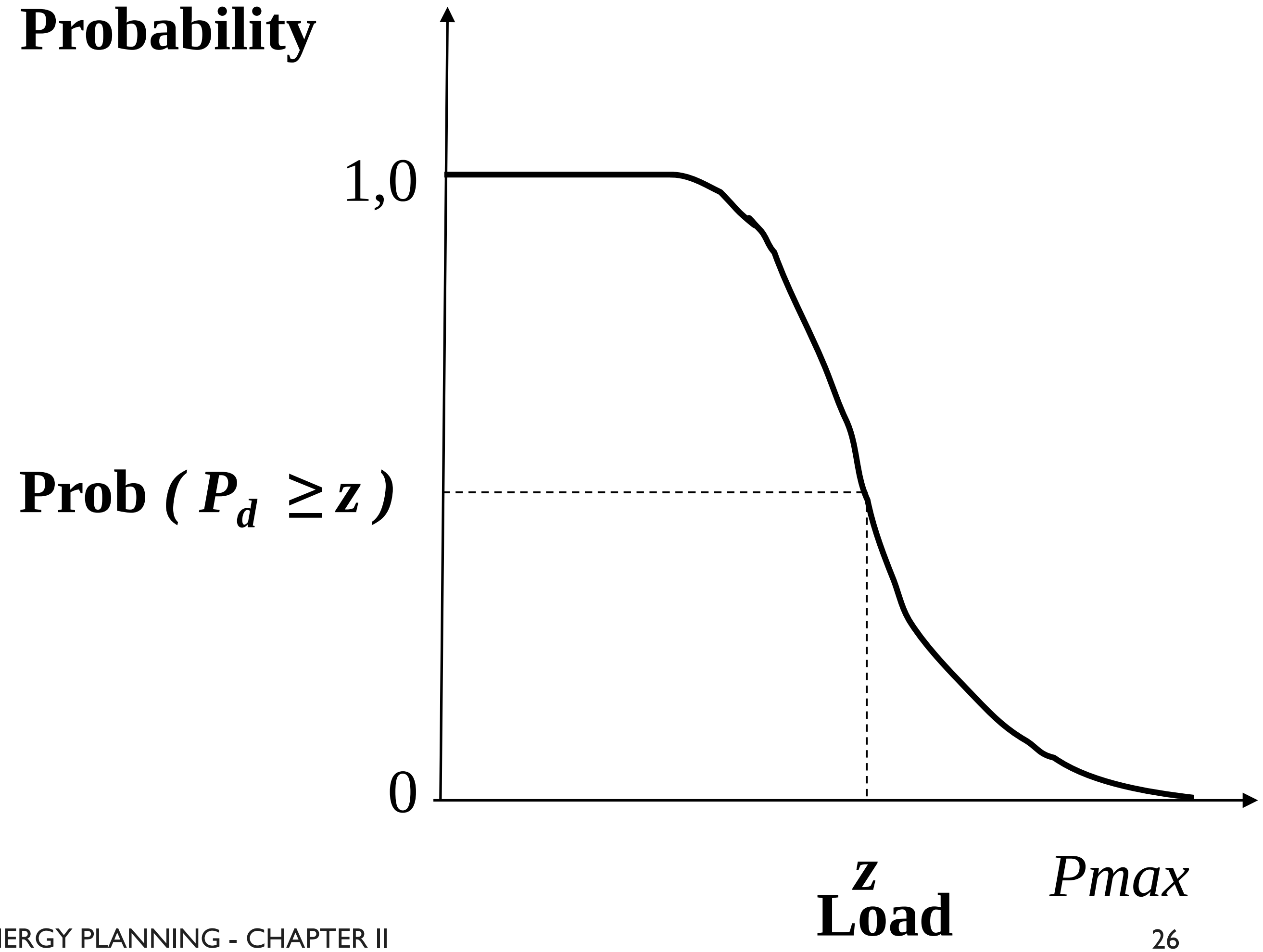
- Critical probability of deficit at peak load
  Prob (P_d > (P_{inst} – P_p)) ≤ Crit
- Critical probability of energy deficit
  Prob ((E_d - E_{disp}) > 0) ≤ Crit 2

Adequacy Evaluation

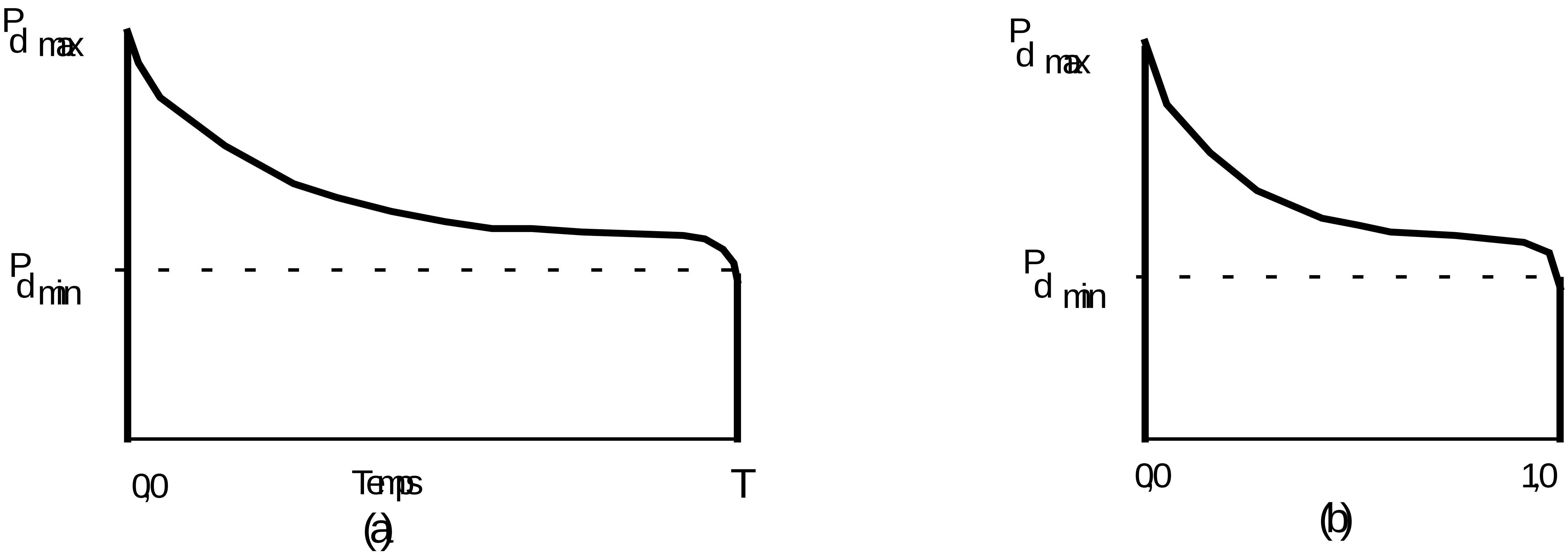
- Modeling the variability of the load
- Modeling the availability of supply
- Simulation of the plants operation

Modeling the variability of the load

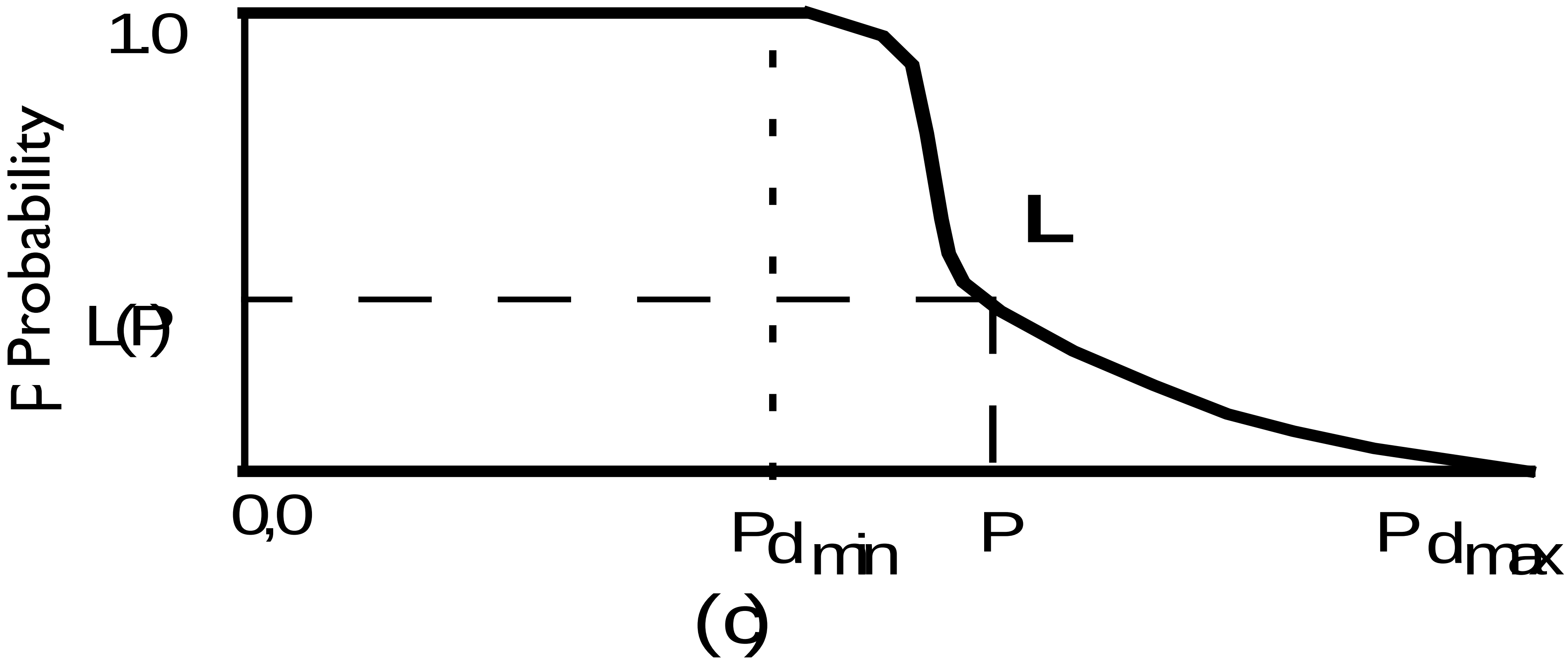




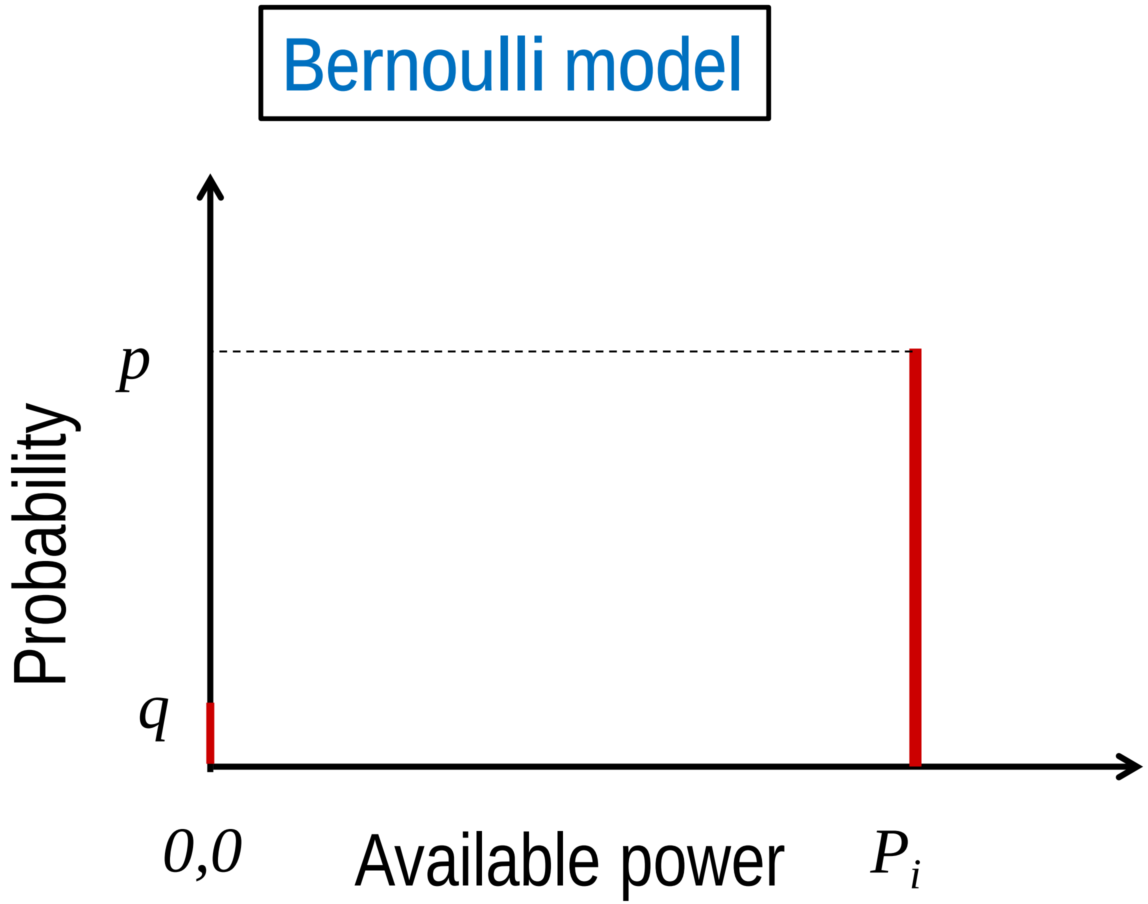
Modeling the variability of the load



Modeling the variability of the load



Modeling the variability of the load



Two possible states:

$Prob\ (P = 0) = q$

$Prob\ (P = P_i) = p$

$p + q = 1.0$

Illustration by simple cases

Case 1: the load does not vary however the supply varies

Example :

2 units of 100 MWe each
Probability of outage of each unit : 5%
Load: 125 MWe

What is the probability of deficit ?
What is the expected value of the power that hasn't been used ?

Case 1: the load does not vary however the supply varies

Answer

Probability of deficit: $1 - 0{,}95^2 = 9.\ 75\%$

Expected value of the load not served: 2.6875 MW

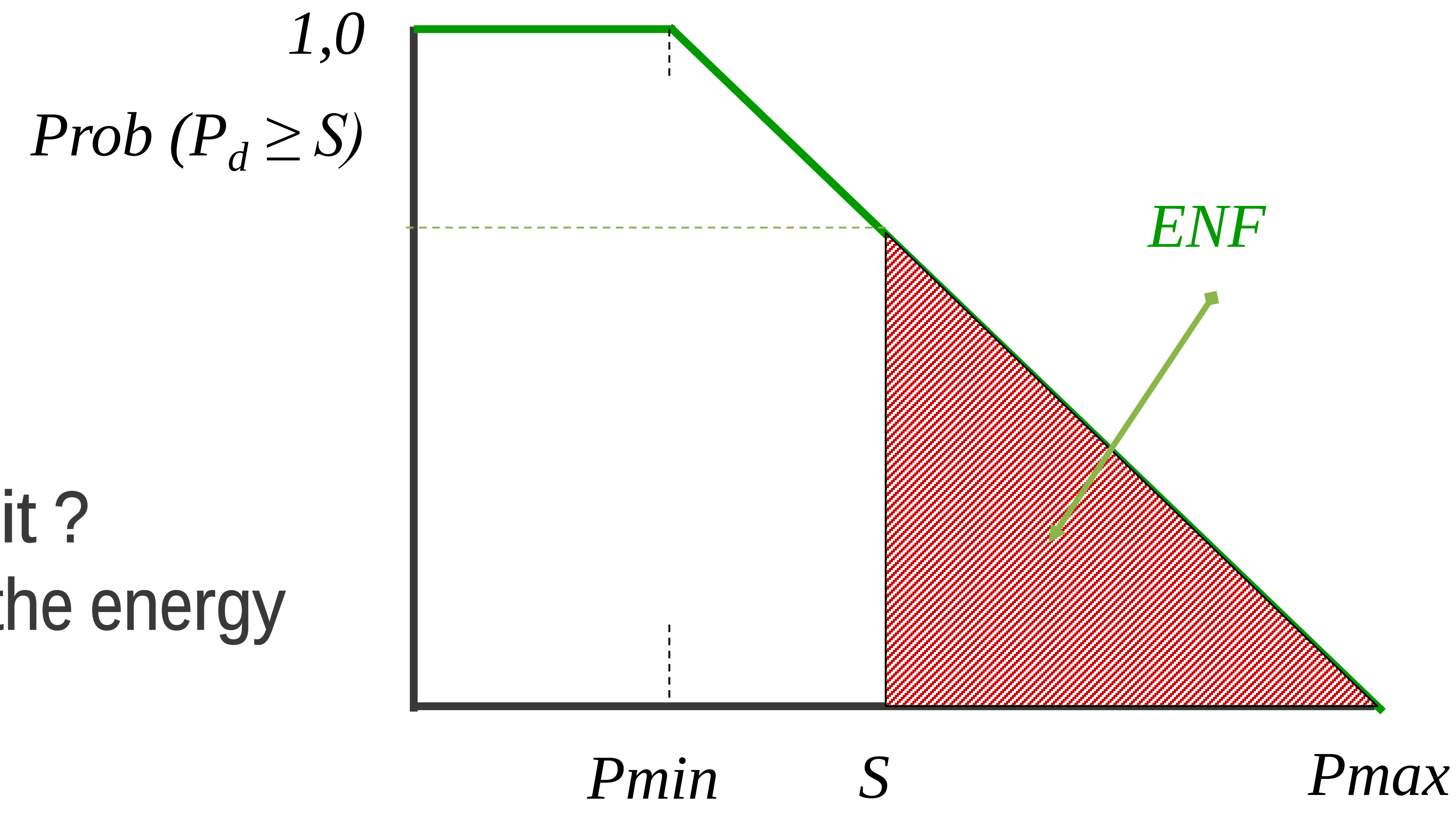
Event	Probability	Déficit (MW)
1) Failure of all units	0.0025	125
2) Failure of only one unit	0.095	25
3) Both units work	0.9025	0

Case 2: The supply does not vary and the variation of the demand is represented by the probability function here below

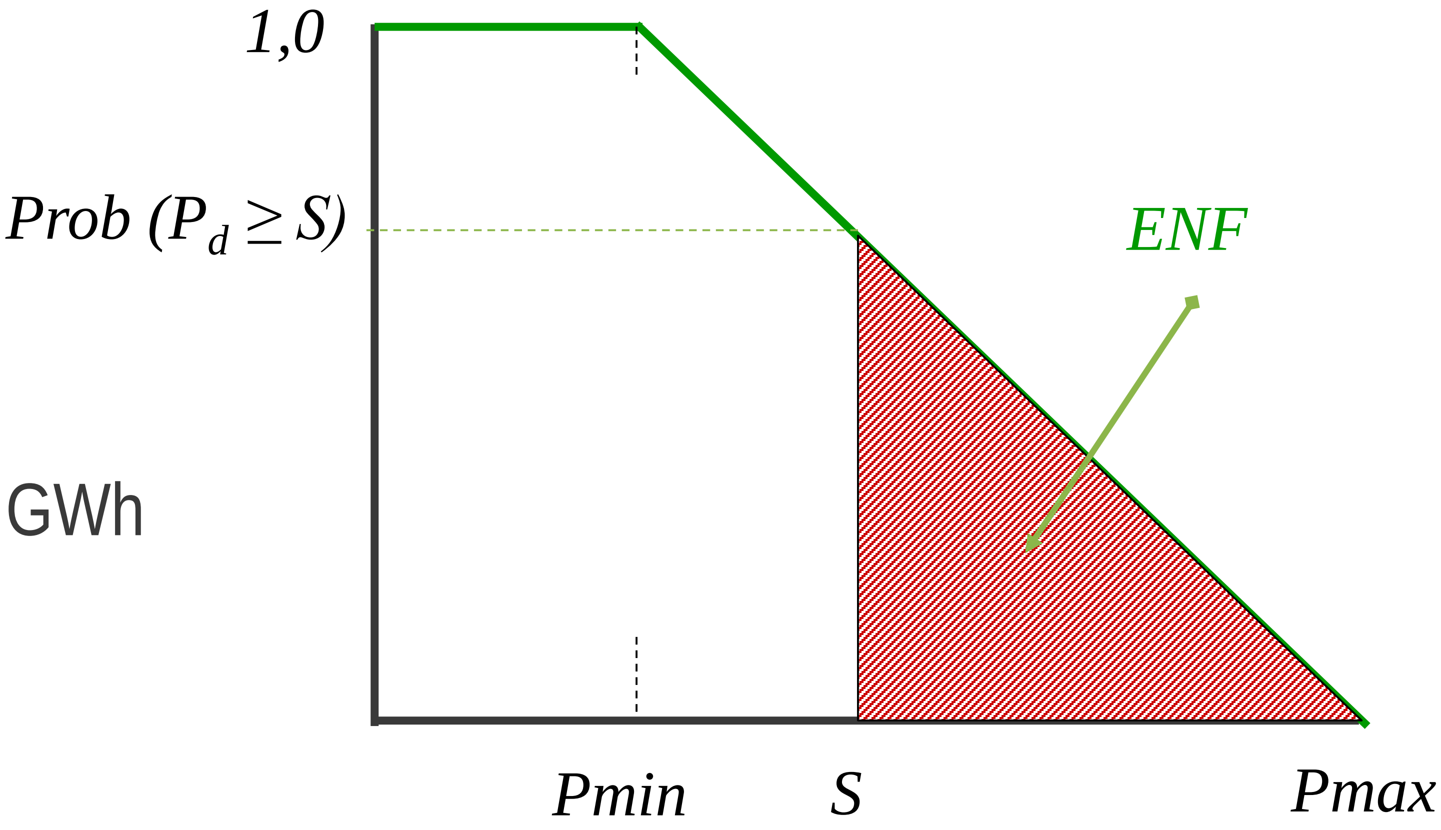
<u>Example</u>

Pmax = 1000 MWe
Pmin = 350 MWe
Supply: S = 700 MWe

What is the probability of deficit ?
What is the expected value of the energy that hasn't been used ?



Case 2: The supply does not vary and the variation of the demand is represented by the probability function here below



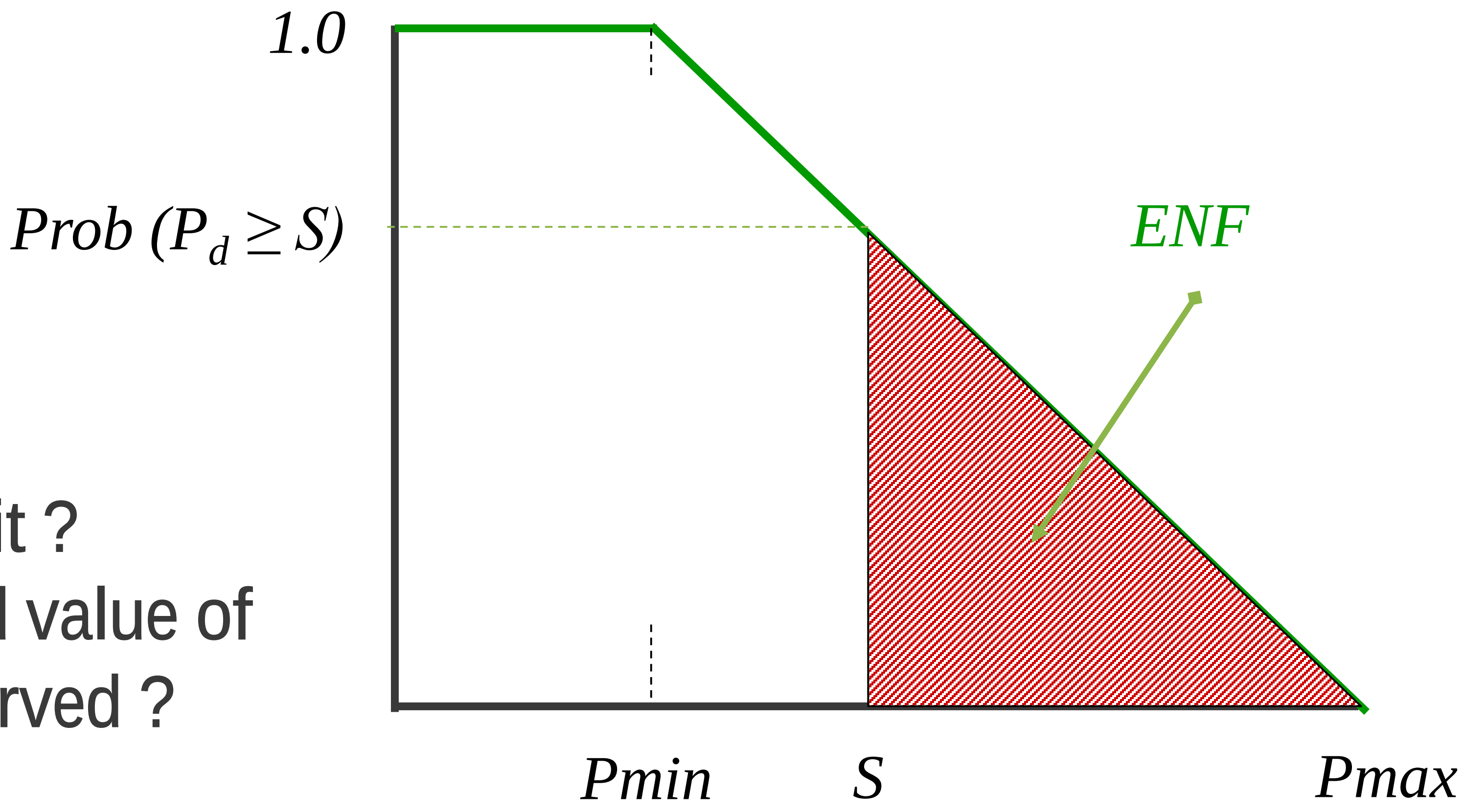
Example

Probability of deficit:
(Pmax-S)/(Pmax-Pmin) = 46%
Expected energy not served: 606.5 GWh

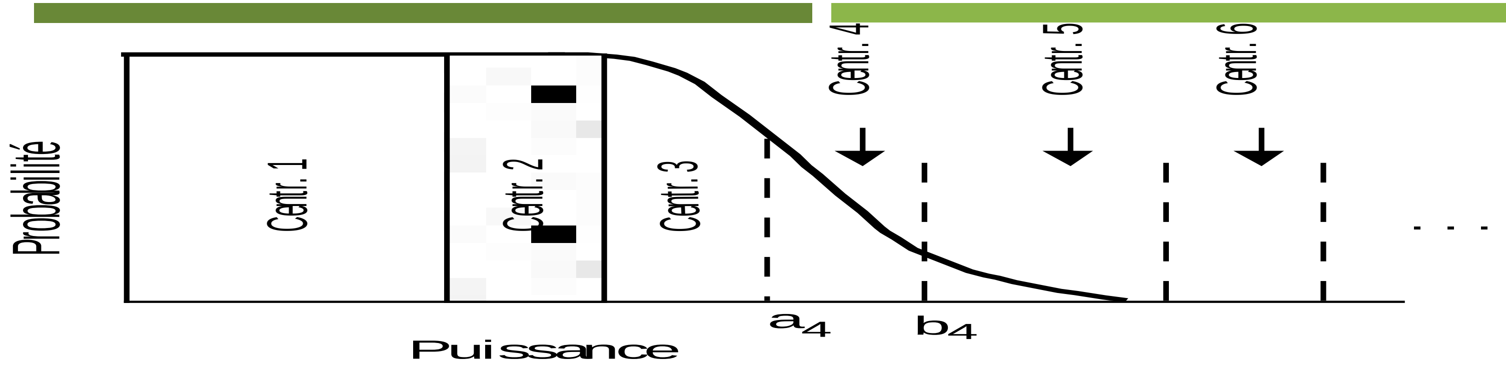
Case 3: The demand and the supply vary; the variation of the demand is represented by the probability function here below

Example

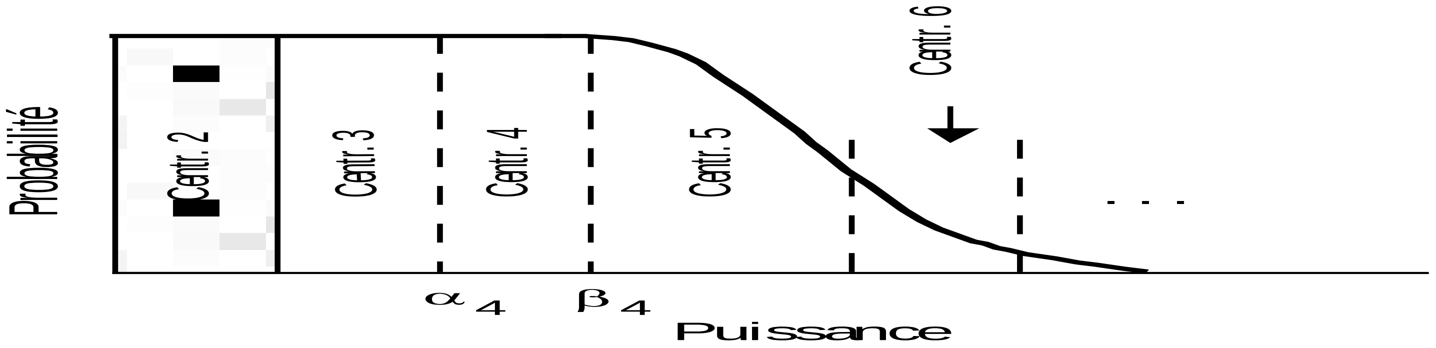
Pmax = 1000 MWe
Pmin = 350 MWe
S = 3 x 350 MWe



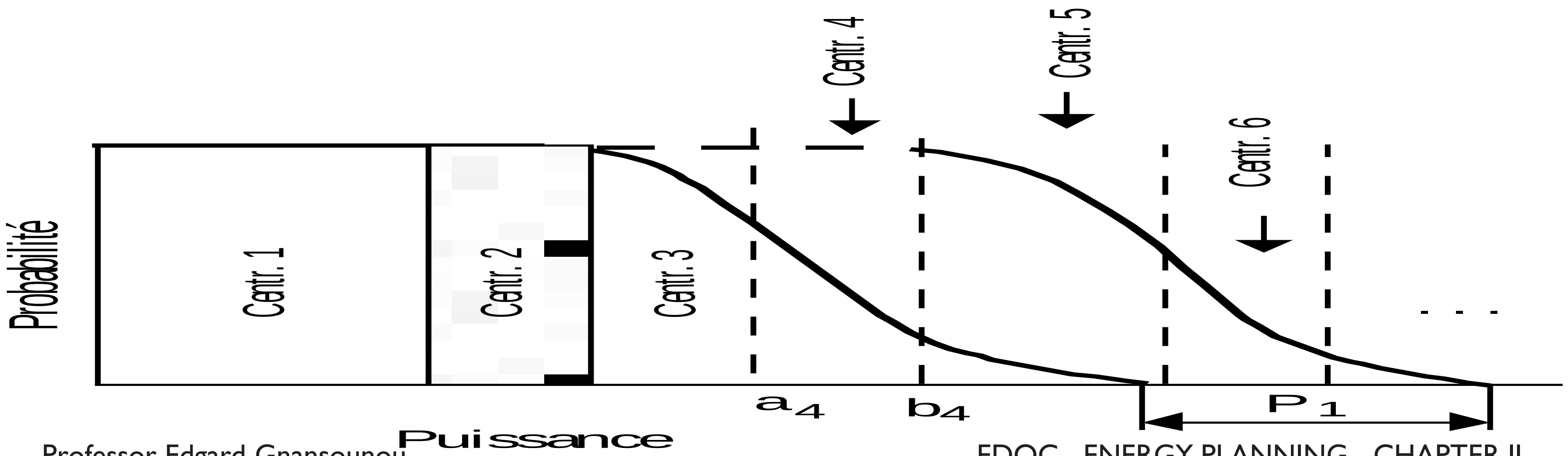
What is the probability of deficit ?
What is the maximum expected value of the energy that hasn't been served ?



$$a_i = \sum_{j=0}^{i-1} P_j$$
$$b_i = a_i + P_i$$
$$P_0 = 0$$



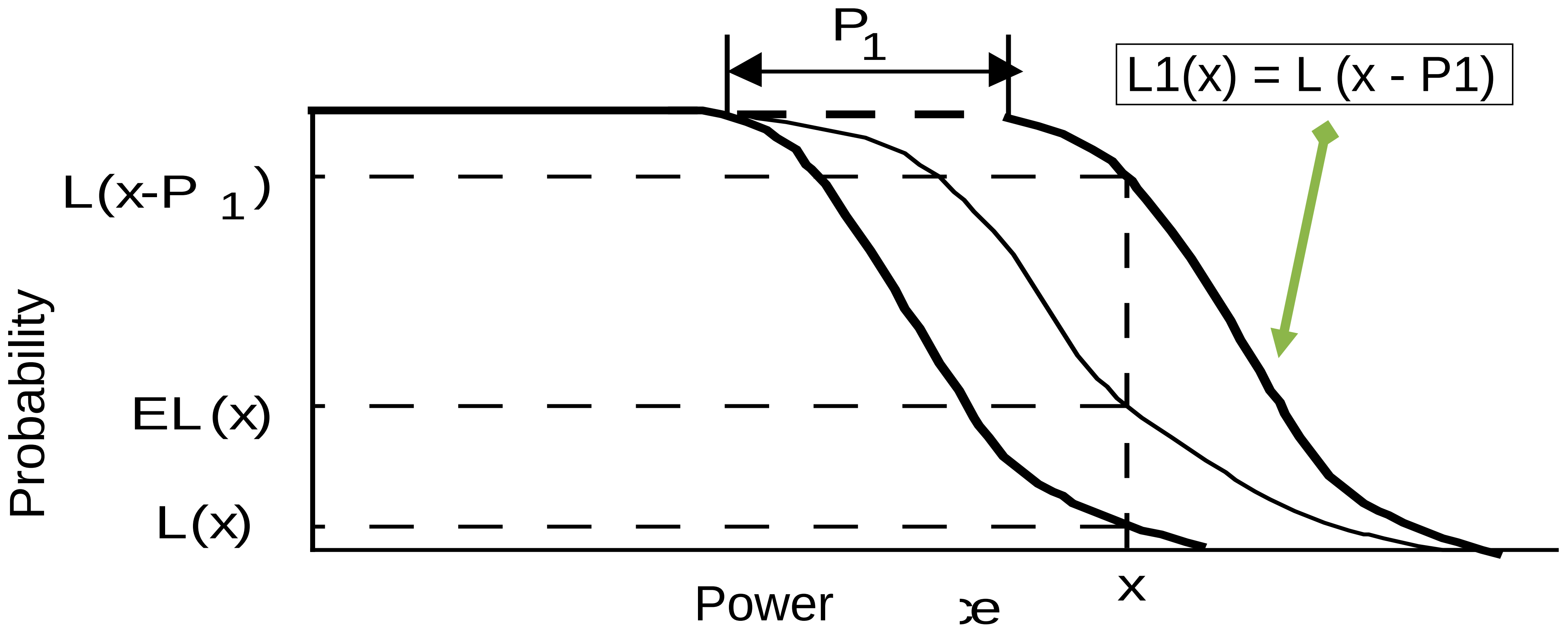
$$\alpha_i = a_i - P_1$$
$$\beta_i = b_i - P_1$$
$$i > 1$$



$$E_i = T \int_{a_i}^{b_i} L(x)\,dx$$

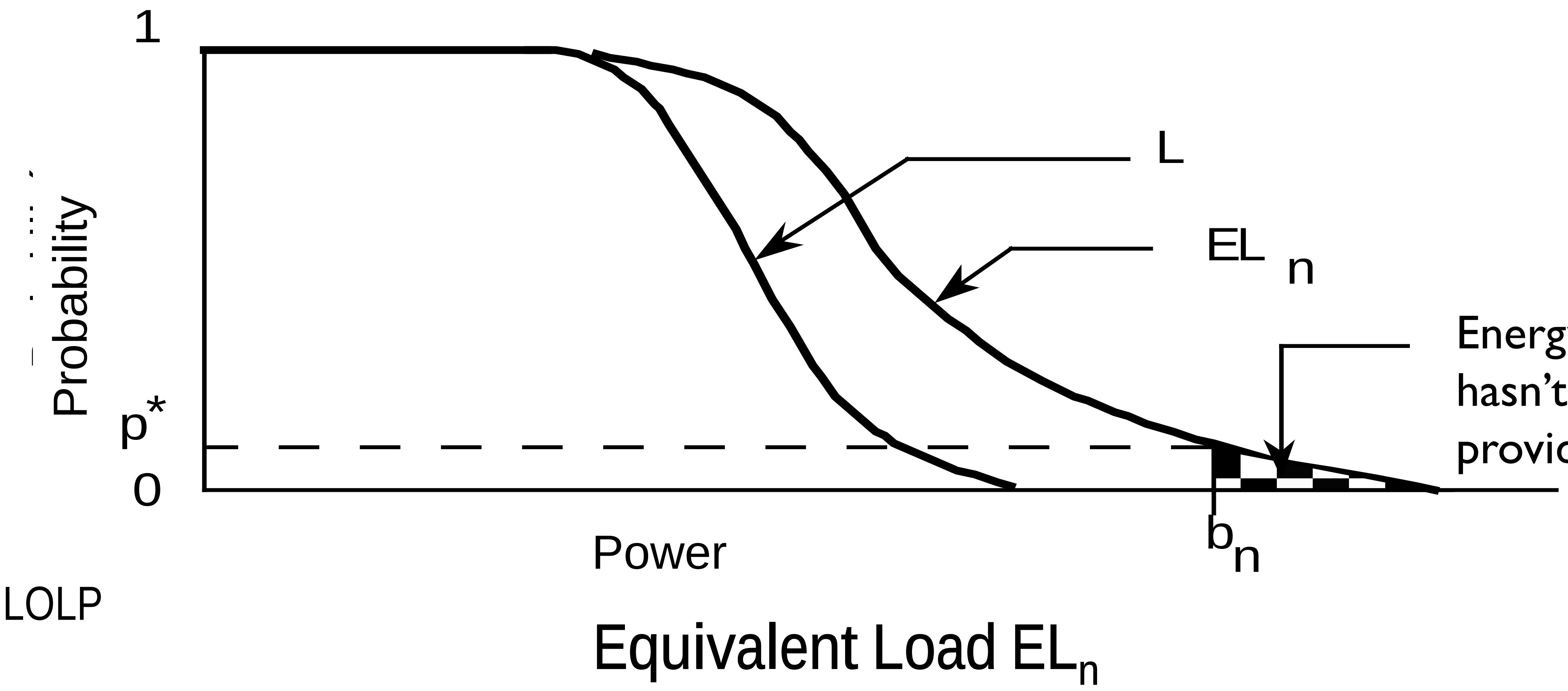
$$E_i = T \int_{\alpha_i}^{\beta_i} L(x)\,dx$$

EQUIVALENT LOAD EL_1



$$EL_1(x) = p_1\, L(x) + q_1\, L_1(x) = p_1\, L(x) + q_1\, L(x - P_1)$$

GENERAL CASE



Ilustration of the General Case with the Case 3: The demand and the supply vary; the variation of the demand is represented by the probability function here below

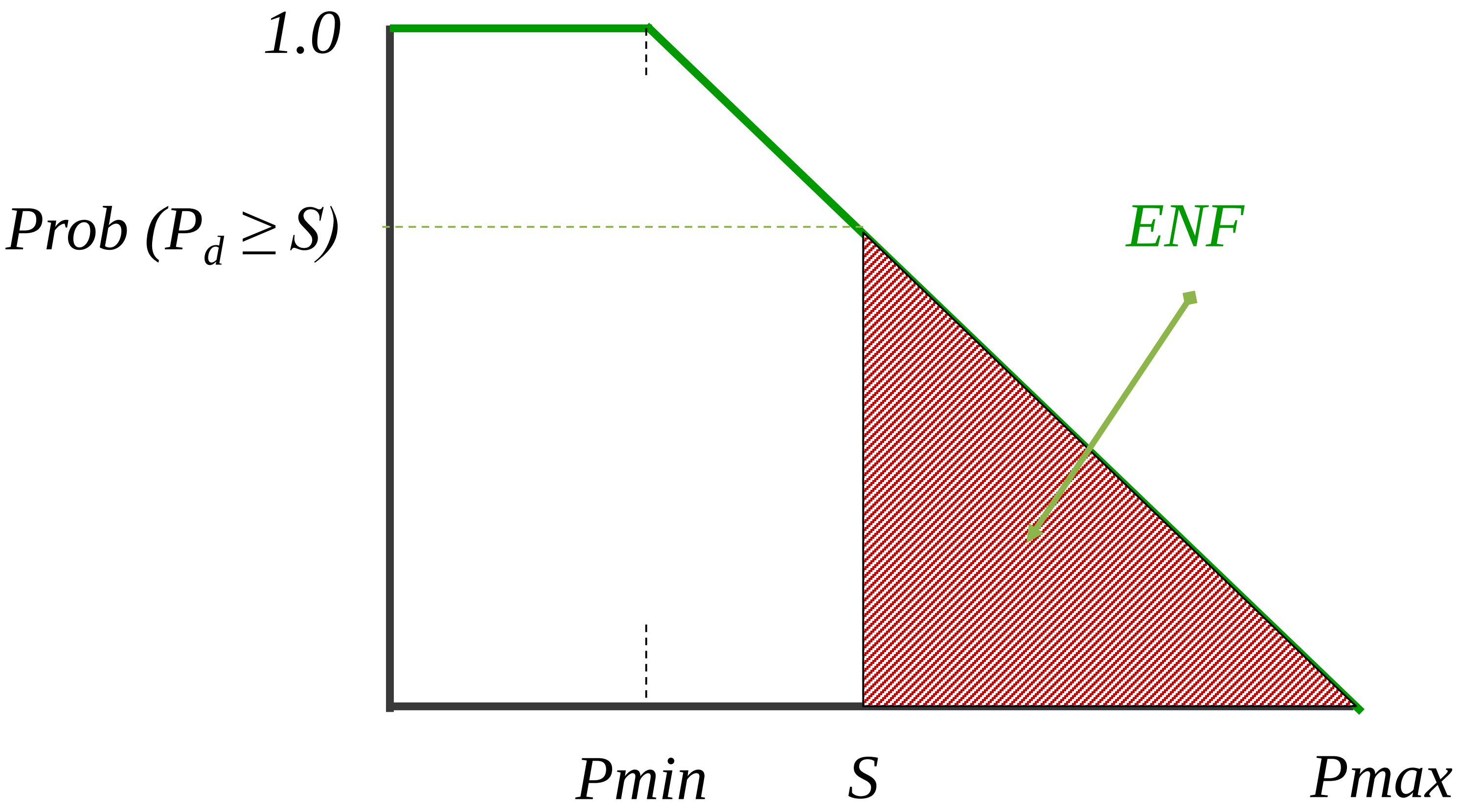
Example

Pmax = 1000 MWe

Pmin = 350 MWe

S = 3 x 350 Mwe

q = 5%



$EL_2(x) = p_2p_1L(x) + p_2q_1L(x-P_1) + q_2p_1L(x-P_2)+q_2q_1L(x-P_1-P_2)$

$EL_2(x) = p^2L(x) + pqL(x-P_u) + qpL(x-P_u)+qqL(x-2P_u)$

$= p^2L(x) + 2pqL(x-P_u) + q^2L(x-2P_u)$

$EL_3(x)=pEL_2(x) + qEL_2(x-P_u)$

$= p^3L(x) + 2p^2qL(x-P_u)+pq^2L(x-2P_u)+qp^2L(x-Pu)+$

$2\ pq^2\ L(x-2P_u)\ q^3L(x-3P_u)$

$= p^3L(x) + 3p^2qL(x-P_u)+3pq^2L(x-2P_u)+q^3L(x-3P_u)$

with $x = 3\ P_u$ we get :

$LOLP = p^3L(3P_u) + 3p^2qL(2P_u)+3pq^2L(P_u)+q^3L(0)$

$= 3p^2q(Pmax-2P_u)/(Pmax-Pmin) + 3pq^2 +q^3$

q^3
$+3pq^2$
$+3p^2q(Pmax-2Pu)/(Pmax-Pmin)$