Chapter 5. System security and ancillary services

Introduction

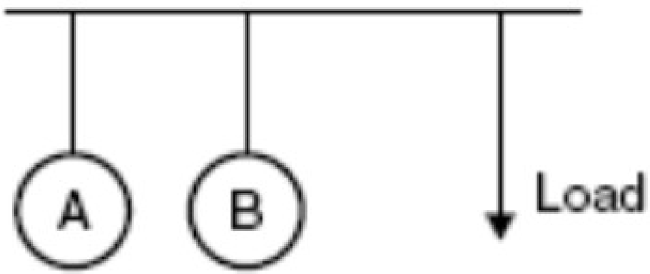
Markets for electrical energy can function only if they are supported by the infrastructure of a power system.

System should continue to operate indefinitely if the conditions do not change but also if some components of the system fail $\Rightarrow$ must operate in a state where it is able to withstand common disturbances.

Set of credible contingencies often contains the outage of all system components taken separately ($N-1$ security criterion).

Illustration of the limitations a $N-1$ security criterion places on operation

System with two generators having a capacity of 100 MW each connected to a load.



Maximum load that can be handled securely is 100 MW and not 200 MW !

Preventive and corrective measures for security

Preventive measures: Designed to put the system in a state such that the occurrence of a credible disturbance does not cause it to become unstable.

Corrective measures: Taken in the aftermath of a disturbance so as to ”save” the system.

Previous illustration: a mix of preventive and corrective actions. You preventively limit the maximum load you can serve but in case of an outage of a generator you may correctively adjust the generating power of the other.

Describing the needs for ancillary services

Needs classified according to three different issues:

[1] Balancing issues
[2] Network issues
[3] System restoration

Classification not perfect. Interactions for example between balancing and network issues.

Ancillary services needed for addressing every of these needs. The services are provided by the generators and the loads.

Balancing issues

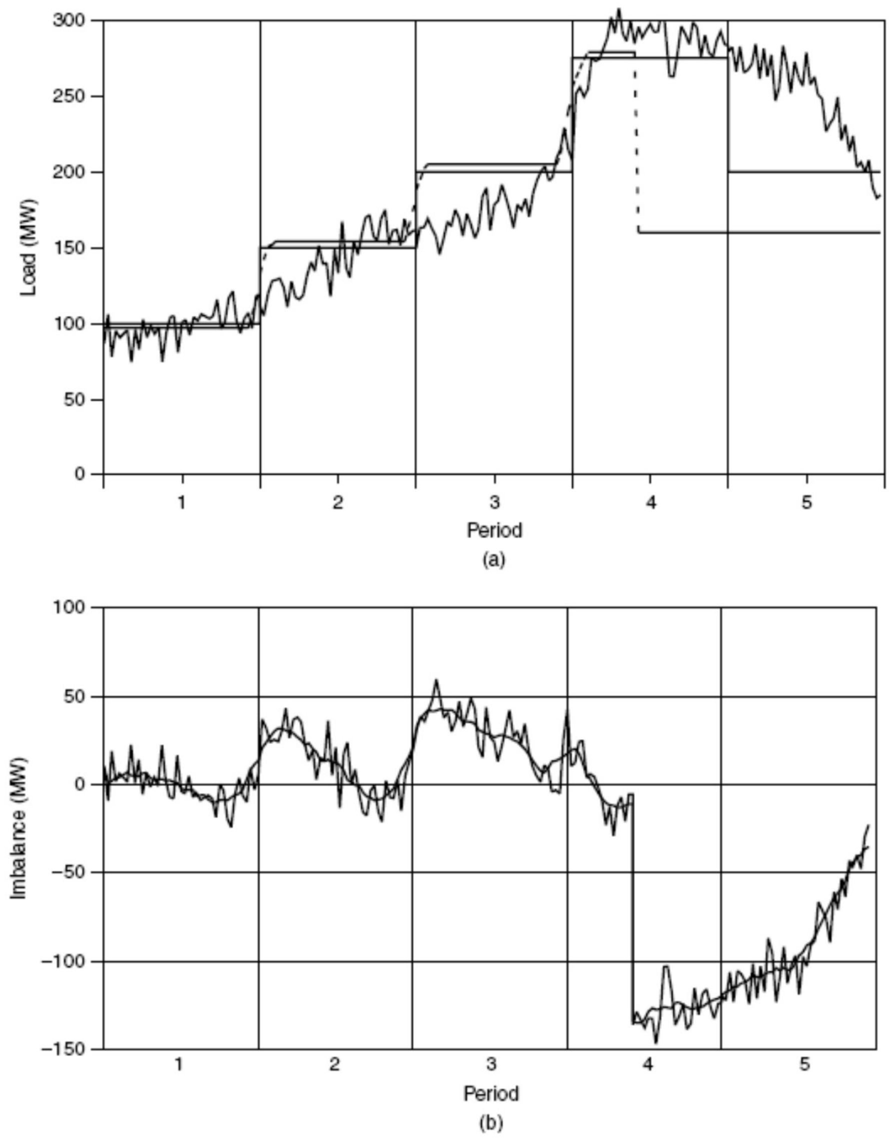
Assumption: all loads and generators connected to the same bus bar.

If too much generation, excess of energy stored by the generators under the form of kinetic energy ⇒ increase of the frequency. If not enough generation, generators release kinetic energy ⇒ decrease of the frequency.

Systems with small inertia more vulnerable to frequency deviations.

Large frequency deviations ⇒ overspeed or underspeed protection systems of generators activated ⇒ increase of the frequency deviations ⇒ . . . ⇒ System collapse.

General philosophy for handling balancing issues: try always to keep the frequency as close as possible to its nominal value.



(a) Load and generation fluctutations. (b) Resulting imbalances.

Imbalances between load and generation have three different components with three different time signatures: (i) rapid random fluctuations, (ii) slower cyclical fluctuations and (iii) occasional large deficits.

System operator can treat them separately and can tailor the different ancillary services it needs to cope with a specific component of the total imbalance.

Regulation service: able to handle rapid fluctuations in loads and small unintended changes in generation. Provided by units that can rapidly increase or decrease their output.

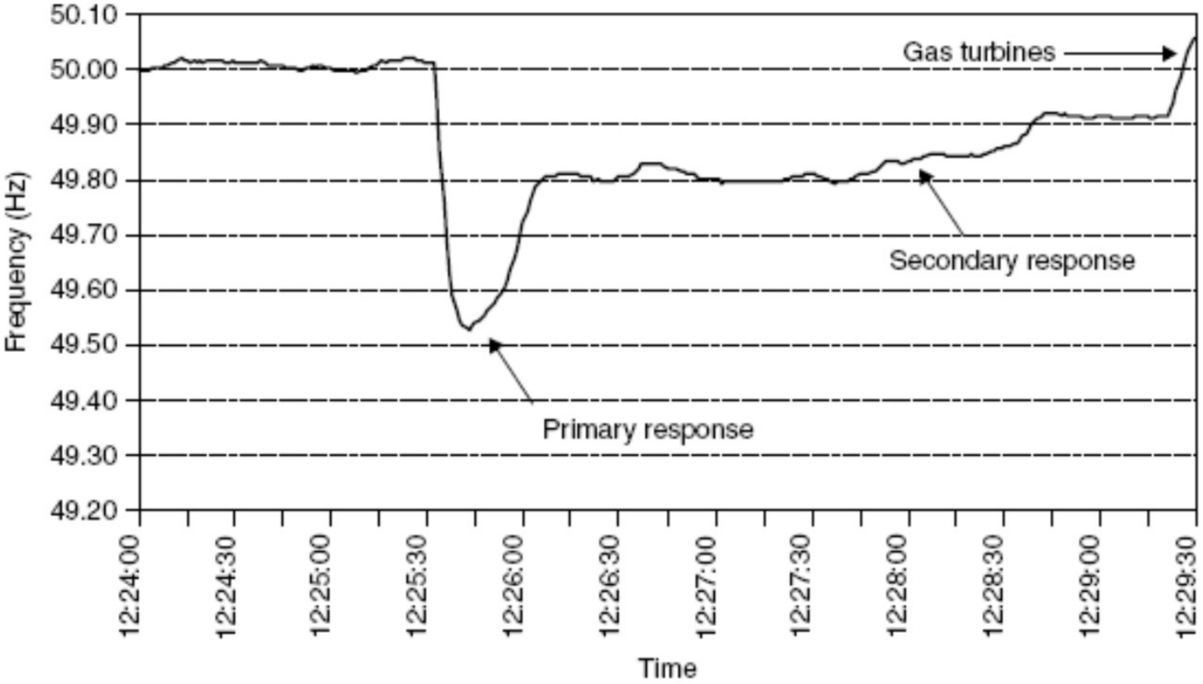
Load-following service: able to handle slower fluctuations, in particular intraperiod changes that the market does not take into account. Both services require more or less continuous actions from the generators providing these services.

Reserve services: designed to handle large and unpredictable power deficits that could threaten the stability of the system. Classified as correctives actions. Obtaining reserve services is however a preventive security action.

Spinning reserve: available very quickly.

Supplemental reserve service: may be provided by units which are not synchronized to the grid but can be brought on line quick.

Customers that agree to be disconnected can also offer a reserve service.



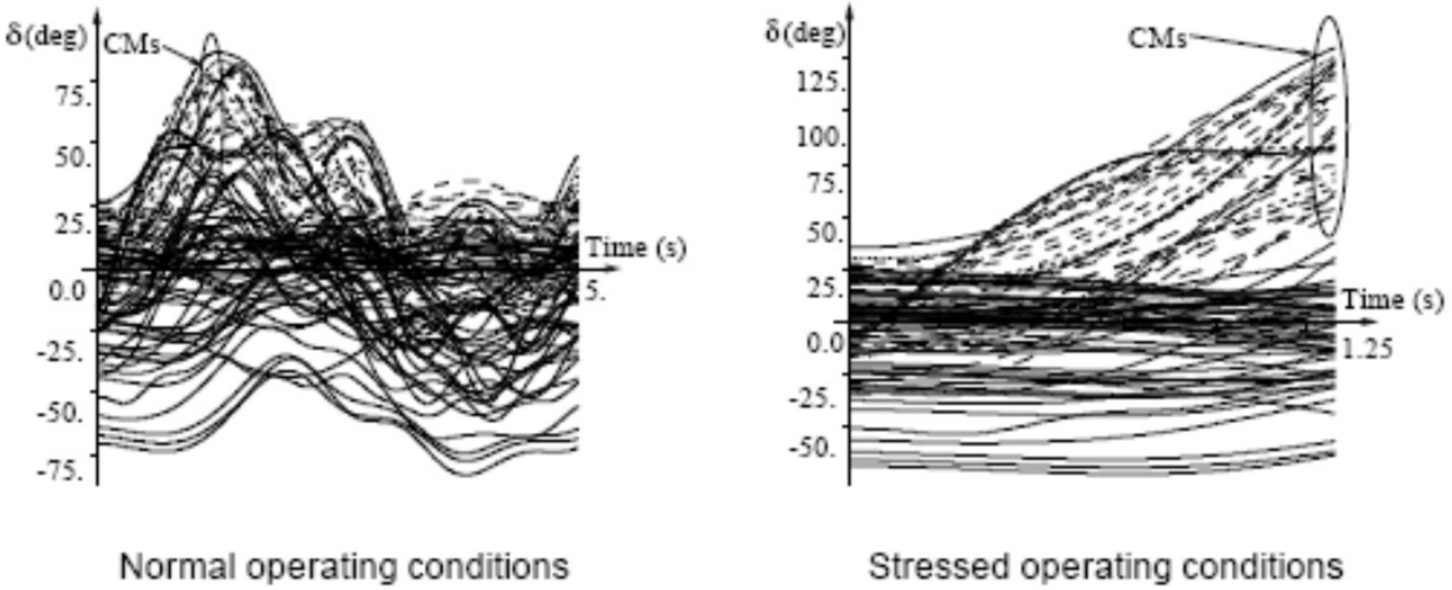
Sequence of events: (a) 1220 MW of generation lost in Great Britain (65 GW of installed capacity) (b) primary response that must be fully available after 10s and sustained for a further 20s succeeds to arrest the frequency drop (c) secondary response that must be fully available 30s after the incident and must be sustainable for a futher 30 min enters into action to bring back the system closer to its nominal frequency (d) gaz turbines enter into action which produce the last increase of the frequency.

Network issues

As loads and generations vary, the flows in the branches and the voltages at the nodes of the network fluctuate. The operator must ensure that the system is always in a safe operating point (e.g., no equipment overloaded, N-1 contingency analysis is OK, etc.)

Destabilization can take different form: cascading failures, voltage collapse of the system, loss of synchronism phenomena, large undamped oscillations that may activate protection relays, etc.

Loss of synchronism and operating conditions



Normal operating conditions

Stressed operating conditions

EPRI 88 machines test system.

Disturbance: three-phase short circuit cleared by opening of a transmission line.

Preventive actions

If the state of the system is such that a credible contingency would trigger an instability, operators must take preventive actions.

Low or negligible cost preventive actions: adjusting the transformer taps, changing the topology of the system, changing the voltage set points of generators, rerouting power using phase-shifting transformers, etc.

High-cost preventive actions: As the loading of the system increases, there comes a point where security can only be ensured by placing limitations on the generation patterns. These limitations carry a very significant cost.

Lot of computation needed for selecting the best actions, especially when complex instability phenomena are considered.

Voltage control and reactive support services

Several reactive resources and voltage control devices (capacitors, reactors, tap-changing transformers, etc.) are typically under the direct control of the operator. However generating units provide the best way to control voltage
$\Rightarrow$ a voltage control service (also called reactive power support service) needs to be defined to specify the conditions under which the system operator can make use of the resources owned by the generating companies.

Specification of the conditions difficult : must consider the operation of the system under normal operation but also unpredictable outages.

Specifications for reactive support services: example

Type of specifications:

[1] keep the voltage at the generator bus node within a certain interval when normal operating conditions (typically, 0.95 p.u. $\leq$ V $\leq$ 1.05 p.u.) (reasons: facilitate voltage regulation at the distribution level, high voltages under normal makes the system more robust to disturbances, etc)

[2] Capability to provide reactive power reserve in case of emergency.

Stability services

System operators may also need to obtain other network security services from generators such as for example:

Intertrip schemes: in the event of a fault, they automatically disconnect some generation and/or some load to maintain the stability of the system.

Power system stabilizers: make adjustments to the output of generators to dampen oscillations that might develop in the network. Can increase the amount of power that can be transmitted in a line.

System restoration

Disturbances may spiral out of control and the entire power system may collapse !

The system operator has the responsibility to restore the system as soon as possible.

But restarting large thermal plants requires a significant amount of power . . . which is not available if the entire system has collapsed.

Some generators (e.g., hydroplants, diesel generators) can however restart in an autonomous way.

The system operator must ensure that enough of these restoration resources are available. This ancillary service is usually called balck-start capability.

Obtaining ancillary services

Previously: we have seen that power system operators need some resources to maintain the security of the system and that some of these resources must be obtained from other industry participants in the form of ancillary services.

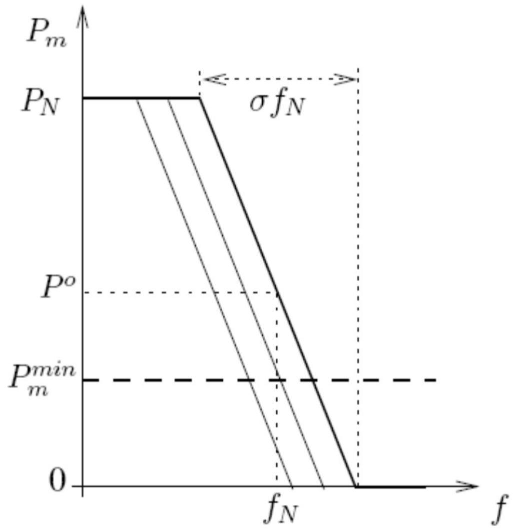
We examine now two mechanisms for obtaining these ancillary servirces
[1] Making the provision of some ancillary service compulsory.
[2] Create a market for these ancillary services.

Choice of one mechanism to the other influenced by the type of ancillary service, the nature of the power system and historical circumstances.

Compulsary provision of ancillary services

As a condition for begin allowed to connect, a category of industry participants is required to provide a certain type of ancillary service. Example, generating units may be required to be to:

- to be equipped with a 4 % droop coefficient (σ) to ensure that all units contribute equally to frequency regulation



- capable of operating with a power factor ($\frac{P}{S}$) ranging from 0.85 lead to 0.9 lag and be equipped with voltage regulators.

The cons for compulsory provision

[1] Unnecessary investments: not all generating units need to take part in frequency control, not all the units need to have power system stabilizers.
[2] Does not leave room for technological improvements or commercial innovation (e.g., you could using IT system provide all types of balancing services by modulating the load).
[3] Not popular. Providers may feel that they are forced to supply a service for which they are not paid (e.g., producing reactive reserves increases losses and the maximum amount of active power that can be produced)
[4] Participants may be unable to provide services (e.g., nuclear units cannot change rapidly their power output). Compulsion therefore not applicable for some services.
[5] Inefficient use of resources. For example, efficient units should not be forced to operate at part load so they can provide reserve.

Market for ancillary services

Long-term contracts are preferred for services in which the amount needed does not change (or very little) with time such as:
black-start capability, intertrip schemes, power-system stabilizers and frequency regulation.

Spot market needed for services in which the needs vary substantially over the course of the day and offers change because of the interactions with the energy market. Last part of the necessary reserve is often provided by a short-term market mechanism.

Markets provide a more flexible and more economical way to provide ancillary services. But not yet clear whether all ancillary services could be provided by markets (e.g., potential abuse of market power for example when the system really rely on a unit for controlling the voltage in a remote part of the system).

Demand-side provision of ancillary services

In a vertically integrated environment, generating units provided all the ancillary services.

In a competitive environment, the demand-side should also be able to offer these services.

All the balancing issues could be tackled in principle by the demand-side.

Demand-side could also in principle help to tackle other instability issues such as voltage instability, loss of synchronism phenomena, damping of oscillations, etc.

HUGE OPPORTUNITIES FOR NEW BUSINESSES

Buying ancillary services

System operator responsible for buying the ancillary services on behalf of the users of the system through a market mechanism.

System operator users pays the providers of these services and recover costs from users.

Needs to buy the optimal amount of services and pays the right price for it.

Users need to pay a fair share of the costs.

Quantifying the needs

Cost/benefit analysis: Level of needs at the point where the marginal cost of providing more security is equal to the marginal value of security.

Marginal cost of security: how much does it cost to increase reliability of the system. Can be defined for example using probabilistic models that for a given level a security give the amount of load that cannot be served during one year.

Marginal value of security: what is the value of an increase of security to the customers.

Question: If the cost is passed on user, what is the incentive for the operator to buy the optimal amount of ancillary services and, to a least extend, at the minimal cost ?

Co-optimization of energy and reserve in a centralized electricity market

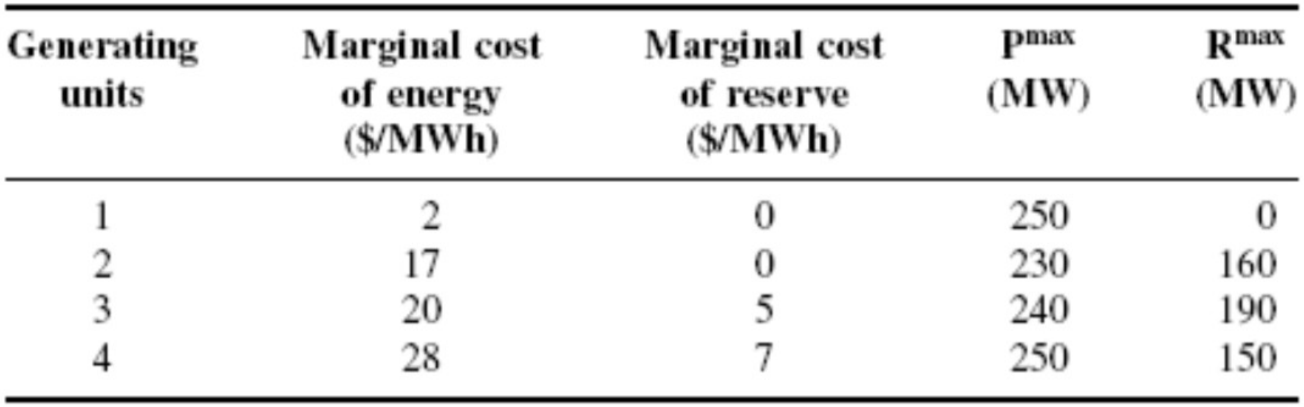
Procurement of electrical energy coupled with the procurement of reserve. Treating these two procurements in separate markets is suboptimal.

Energy and reserve should be offered in joint markets that should be cleared simultaneously to optimize costs.

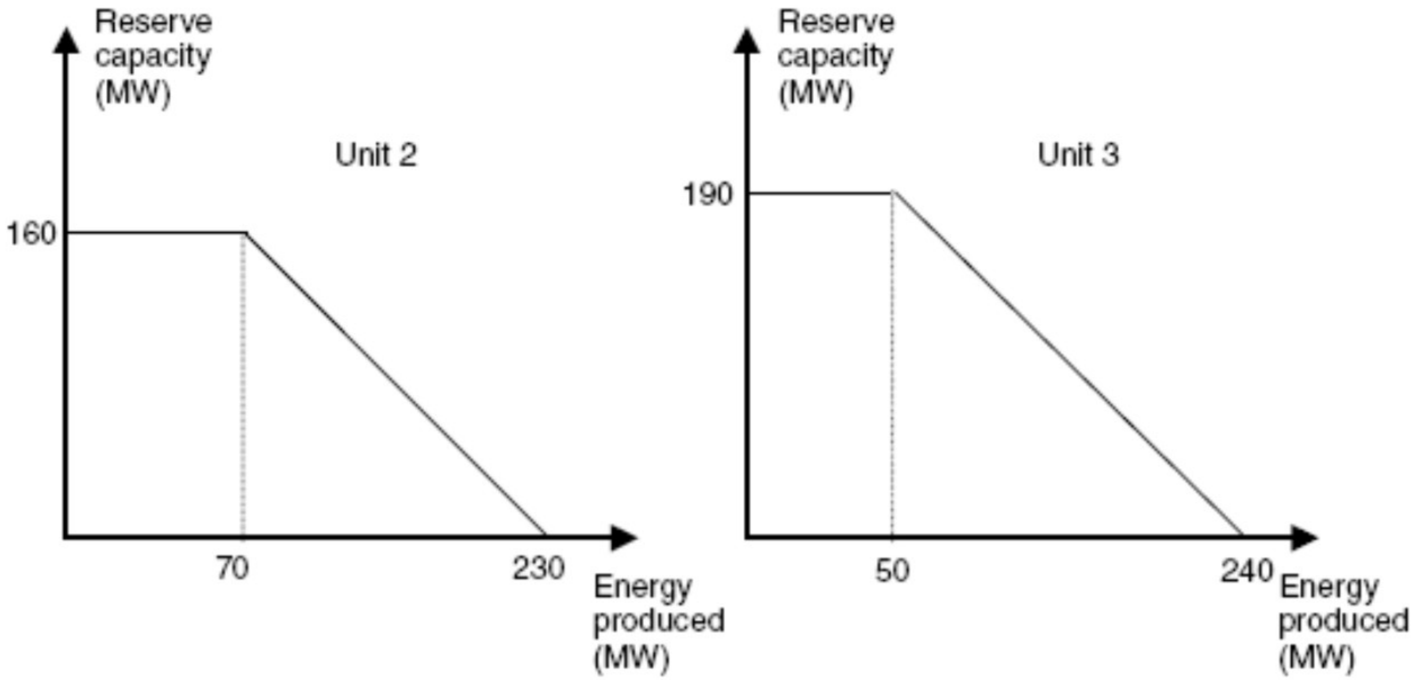
Consider it was not the case. Generators would first sell only a percentage of the energy they would sell and keep the rest of their capacity for the spinning market. As a result, in the energy market
[1] Generators which are more expensive may have to produce more energy
[2] Generators that provide spinning reserves may be less efficient that if they would be running at full load (average price per MWh higher).
$\Rightarrow$ price of electrical energy may be higher.

An example of co-optimization

System where production varies in between 300 and 720 MW; minimum of reserve needed to maintain security for all loading condition 250 MW.



Generating units	Marginal cost of energy ($/MWh)	Marginal cost of reserve ($/MWh)	P^{max} (MW)	R^{max} (MW)
1	2	0	250	0
2	17	0	230	160
3	20	5	240	190
4	28	7	250	150


Reserve capacity (MW)
Unit 2
160
70
230
Energy produced (MW)
Reserve capacity (MW)
Unit 3
190
50
240
Energy produced (MW)

Optimisation problem

Optimisation variables: P_1, P_2, P_3, P_4, R_1, R_2, R_3, R_4

Objective function :

min$(2P_1 + 17P_2 + 20P_3 + 28P_4 + 0R_1 + 0R_2 + 5R_3 + 7R_4)$

Constraints:

Balance between production : $P_1 + P_2 + P_3 + P_4 = D$

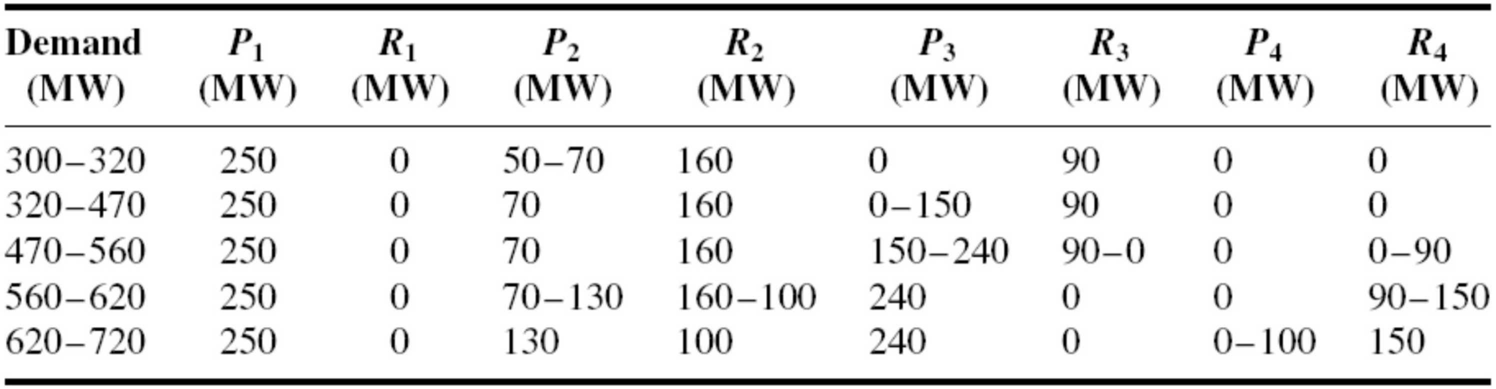
Minimum reserve requirement : $R_1 + R_2 + R_3 + R_4 \geq 250MW$

Limits on production: $0 \leq P_1 \leq 250$, $0 \leq P_2 \leq 230$, $0 \leq P_3 \leq 240$,$0 \leq P_4 \leq 250$

Limits on reserve : $R_1 = 0$, $0 \leq R_2 \leq 160$, $0 \leq R_3 \leq 190$, $0 \leq R_4 \leq 150$

Limits on capacity : $P_1 + R_1 \leq 250$, $P_2 + R_2 \leq 230$, $P_3 + R_3 \leq 240$, $P_4 + R_4 \leq 250$

Results: dispatch



Demand (MW)	P_1 (MW)	R_1 (MW)	P_2 (MW)	R_2 (MW)	P_3 (MW)	R_3 (MW)	P_4 (MW)	R_4 (MW)
300–320	250	0	50–70	160	0	90	0	0
320–470	250	0	70	160	0–150	90	0	0
470–560	250	0	70	160	150–240	90–0	0	0–90
560–620	250	0	70–130	160–100	240	0	0	90–150
620–720	250	0	130	100	240	0	0–100	150

Figure: Marginal price of producing energy and reserves

Results: marginal prices

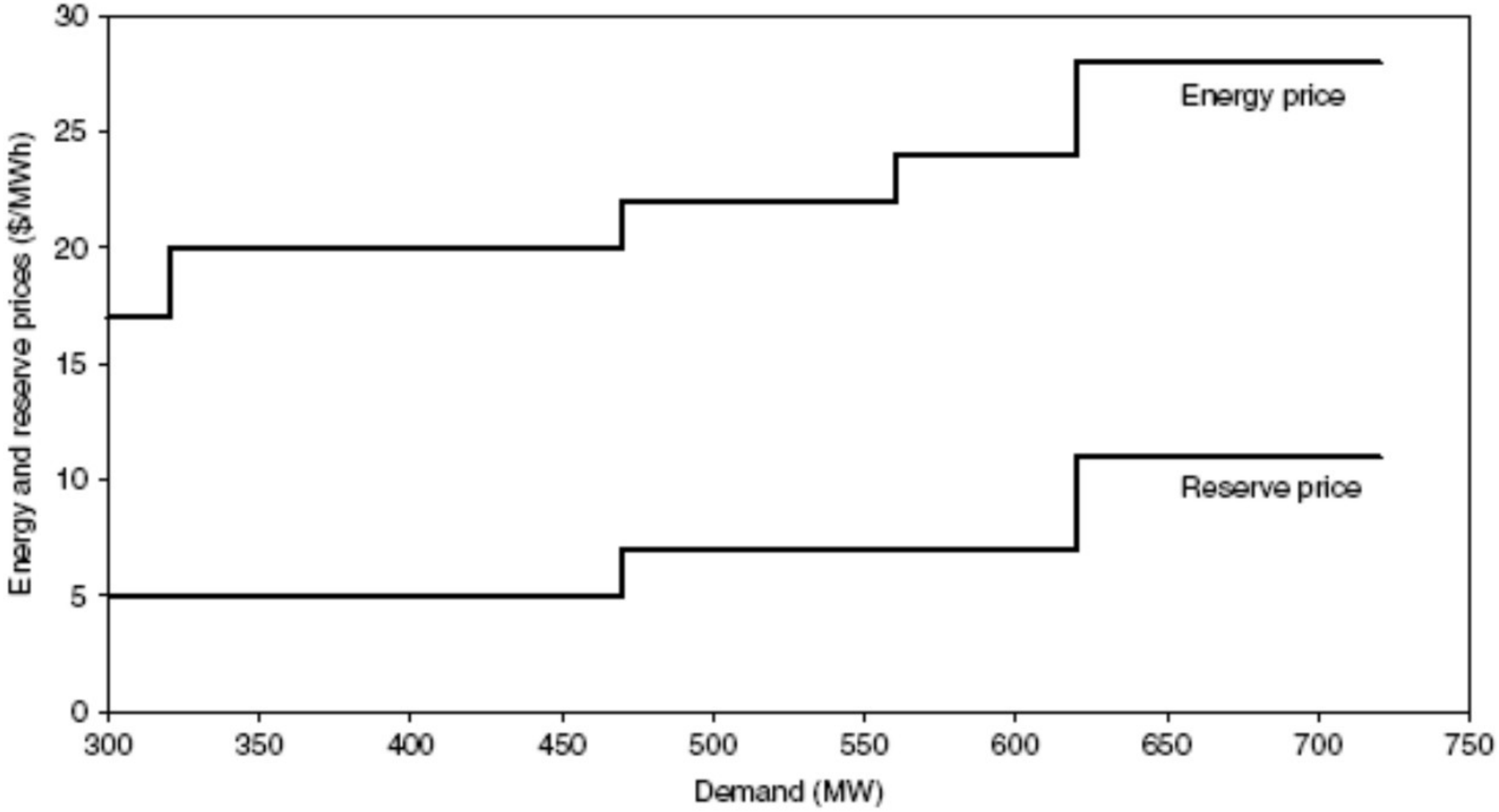


Figure: Marginal price of producing energy and reserves

Allocating the costs

Not all the consumers value system security equally. Example: cost of service interruption greater for a semiconductor factory than a residential customer ⇒ Customers should be able to pay for a desirable level a reliability. But selling customized-reliability too difficult too achieve in practice.

Requirement for load following and regulation services depend on the customers. Typically, industrial customers need more regulation ⇒ cost should be allocate according to the type of the load to avoid to have a cluster of customers that subsidizes another.

In practice, since all users get the same level of security, cost of the ancillary services is shared among all users of some measure of their use of the system, typically the energy consumed or produced.

Homework

For a group of students, describe in details the control schemes that are used in country of your choice for handling all the balancing issues.

For a group of students, present the paper "Design of ancillary service markets" from Shmuel S. Oren.