Engineering, Economics & Regulation of the Electric Power Sector

ESD.934, 6.974

Session 17
Module F

Electricity tariffs

Prof. Ignacio J. Pérez-Arriaga

Study material

❑ Florence School of Regulation (FSR), "Design of electricity tariffs" <Tutorial text>

Readings

❑ Severin Borenstein, Michael Jaske, and Arthur Rosenfeld, "Dynamic Pricing, Advanced Metering and
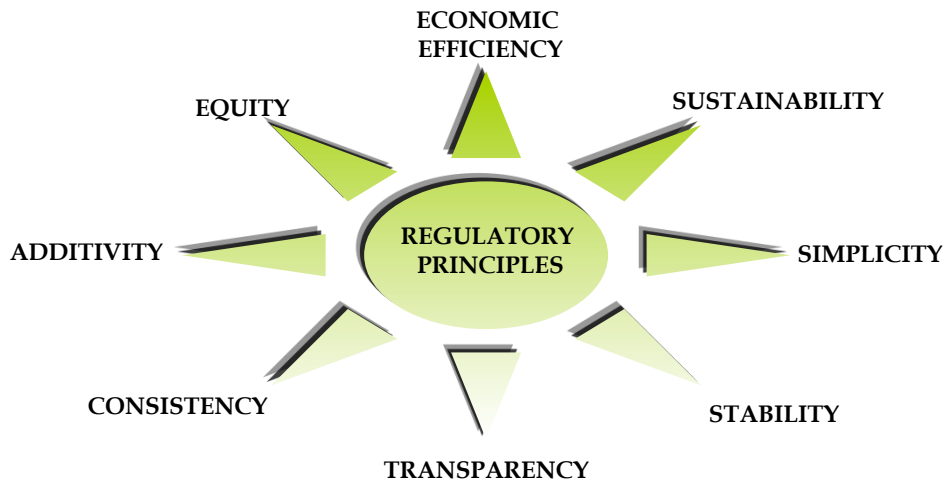❑ Demand Response in Electricity Markets", report CSEM WP 105, UCEI, 2002

Outline

❑ **General principles**

➡ ◆ **Regulatory principles**

◆ Structure

◆ Integral & access tariffs

❑ A conceptual model for tariff design

◆ Specify tariff structure

◆ Assign each cost component

◆ Compute tariffs for end users

Regulatory principles

Regulatory principles

❑**Sustainability:** guarantee of recovery of all regulated costs so that the electrical power sector is economically viable

❑**Equity or Non Discrimination** in the allocation of costs to consumers: Same charge should apply to the same provision of a service, regardless the end use of the electricity.

    ❑This would be in line with a cost allocation procedure based on cost causality

Regulatory principles

❑**Economic efficiency:** Two types are considered:
  - ➤ *Productive:* produce the good or service at minimum cost & meeting prescribed quality standards
  - ➤ *Allocative efficiency*: promote efficiency in consumption of the good in the short & long term

Tariffs must sent economic signals that promote efficient operation & investment. This requires that costs should be assigned to those who are responsible for them *(criterion of **cost causality**)*
  - ➤ Then, use marginal costs / prices whenever possible
  - ➤ If there are still costs to be assigned
    - • apply "cost causality" as far as it is possible
    - • &, finally, try to minimize any inevitable distortion in the economic decisions of the consumers

7

Regulatory principles

❑**Transparency:** in the methodology, so that all employed criteria & procedures are made public

❑**Stability:** in the adopted methodology, so that the concerned agents have the least possible regulatory uncertainty. Stability is compatible with a gradual process of adaptation of the present tariffs to the new system

❑**Simplicity:** in the methodology & its implementation, as far as possible

8

4

Regulatory principles

❑ **Additivity:** derived from the principles of efficiency & sustainability. End user tariffs must be the outcome of adding all applicable cost concepts

❑ **Consistency:** with the specific regulatory process of each country

❑ **Other principles:**

➤ **Universal service:** everybody must have access to electricity

➤ **Protection** of low income consumers

➤ **Protection** of the environment

9

Conflicts among principles (1)

Examples:

❑ The simplest way of recovering costs is the application of an average flat charge, but this is economically inefficient

➔ *Efficient tariffs will not be simple, in general*

❑ Efficiency is optimized if marginal costs / prices are applied, but frequently marginal costs / prices do not recover total costs *(this is the case of the distribution & transmission networks)*

❑ The allocation of costs by strict efficiency criteria may violate the principle of equity or non discrimination *(e.g. Ramsey pricing is efficient but discriminatory)*

10

Conflicts among principles (2)

➔ It is necessary to establish a priority among principles & to reach reasonable agreements on how to proceed. This may depend much on the context within which the regulation takes place.

11

Regulatory principles
A pragmatic summary

❑ Tariffs must comply with the accepted regulatory principles. At least they should:
- ◆ Guarantee recovery of the total regulated cost for each activity
- ◆ Be additive
- ◆ Be reasonably efficient
  - ➢ Send adequate economic signals both in the short & the long term
- ◆ Be simple & transparent

12

Hints for pragmatic solutions

❑ Adopt **tariffs with different components**, so that it is possible to send several simultaneous signals:

◆ **Time differentiation** (since the cost of the system depends on the considered time): time-dependent tariffs

◆ **Short-term energy signals** (as close as possible to real-time ➜ meant to promote efficient system operation): the marginal cost of energy (€/kWh)

◆ **Long-term signals** (meant to promote efficient investments & to recover total costs of the activity): by means of a fixed term (€) &/or a capacity component (€/kW)

◆ **Locational signals** (in the network): geographically differentiated tariffs

13

Outline

❑ **General principles**

◆ Regulatory principles

➡ ◆ **Structure**

◆ Integral & access tariffs

❑ A conceptual model for tariff design

◆ Specify tariff structure

◆ Assign each cost component

◆ Compute tariffs for end users

14

The **structure of the tariff** must be consistent with the **cost function** associated to each cost component (e.g.: the procedure for network planning) & with the known **characteristics of consumption** *(via metering &/or estimation)*

Known characteristics of Consumption (metering): Capacity(t) & Energy(t)

Consistency

Tariff structure

a.P + b.E + c

Cost function

Cost = f(Pj,Ej)
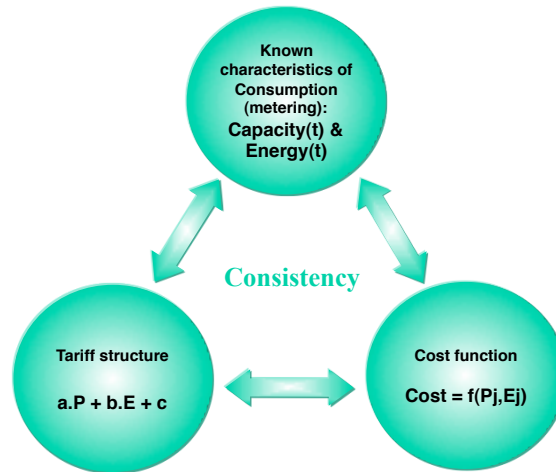
Example of tariff structure

		Winter			Summer		
		Peak	**Intermediate**	**OFF-peak**	**Peak**	**Intermediate**	**Off-peak**
LV ‹1kV	1 tz.	€/kW €/kWh €/customer					
	2 tz.	€/kW €/kWh €/customer			€/kW €/kWh €/customer		
	3 tz.	€/kW €/kWh €/customer		€/kW €/kWh €/customer	€/kW €/kWh €/customer		
MV ›1kV y ‹33kV	3 tz.	€/kW €/kWh €/customer		€/kW €/kWh €/customer	€/kW €/kWh €/custom		
	6 tz.	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer
HV ›33kV y ‹72kV	6 tz.	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer
VHV ›72kV y ‹220kV	6 tz.	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer	€/kW €/kWh €/customer

16

Outline

❑ **General principles**
  - ◆ Regulatory principles
  - ◆ Structure
  → ◆ **Integral & access tariffs**

❑ A conceptual model for tariff design
  - ◆ Specify tariff structure
  - ◆ Assign each cost component
  - ◆ Compute tariffs for end users

17

Integral & access tariffs

❑ There are two basic types of tariffs
  - ◆ Network access tariffs: for qualified consumers
  - ◆ Integral tariffs: for captive (non-qualified) consumers or those who (may) prefer to stay with a regulated tariff

❑ The network access tariff must be a component of the integral tariff
  - ◆ Here it will be assumed that the network access tariff includes
    - ➢ Network charges
    - ➢ Other regulatory charges that apply to all consumers

18

Typical components of integral & access tariffs

- ❑ Energy
- ❑ Capacity charge (long term guarantee of supply)
- ❑ Ancillary services costs
- ❑ Extra costs due to technical constraints
- ❑ Network losses
- ❑ **Transmission and Distribution network charges**
- ❑ **Regulatory charges** *(some examples)*:
  - ◆ **Institutions (Market Operator, System Operator and Regulatory Commission)**
  - ◆ **Incentives to promote cogeneration and renewables**
  - ◆ **Domestic coal support, nuclear moratorium & other nuclear costs**
  - ◆ **Compensations to non peninsular territories**
  - ◆ **Stranded costs: competition transition charges**
- ❑ **Commercialization (retailing) charges**
(belong to both types of tariffs)

ACCESS TARIFF (only explicit for qualified consumers)

INTEGRAL TARIFF (for non qualified consumers)

19

Outline

- ❑ General principles
  - ◆ Regulatory principles
  - ◆ Structure
  - ◆ Integral & access tariffs
- ➡️ ❑ **A conceptual model for tariff design**
  - ◆ Step 1. Specify tariff structure
  - ◆ Step 2. Assign each cost component
  - ◆ Step 3. Compute tariffs for end users

22

Electricity Tariffs
A conceptual model

❏ The basic procedure

Step 1. Characterize the consumer types & specify the tariff structure

Step 2. Assign each one of the considered costs

➤ to each time zone that has been adopted in the tariffs' structure (ideally each hour of the year)

➤ or per consumer annual charge (commercialization)

➤ or just once (network connection charge)

➤ or as percentages of the final tariff (a variety of regulatory charges)

Step 3. Compute each one of the tariffs by aggregation

23

Step 1. Specify tariff structure & characterize consumer types

A. Define the tariff structure
  ◆ voltage levels
  ◆ time zones (seasons / time-of-day)
  ◆ fixed, capacity &/or energy charges
  ◆ consumer types
  ◆ utilization factors

B. Determine / estimate the aggregated profile of the load for each
  ◆ time zone
  ◆ consumer types
  ◆ & voltage level

24

Time zones

❑Time zones allow one to establish tariffs that are consistent with the desired time differentiation

❑Time zones must take into account the available metering capabilities

❑Time zones must send economic signals to consumers regarding the cost of electricity at differen times. Then

◆All hours in the year must be classified regarding the level of expected incurred **supply costs** (this is better adapted to generation costs) as well as the **demand level** (this is more adapted to network costs)

26

Energy & capacity charges

❑ Tariff structure must also be consistent with
   ◆**The cost function for each cost component**
   ◆**The available information on each consumer type**

❑ This available information depends on the available meters and the format of the electricity contracts
   ◆Demanded power measurements: maximum demanded power, average demanded power per time zone, average demanded power
   ◆Contracted capacity: annual, per time zone
   ◆Energy measurements

❑ A good tariff structure should incentivise an upgrade of the capability of electricity meters
   ◆Cost of new meter vs. savings in electricity bill

28

A refinement
Utilization factor (UF)

❑ UF = total consumed energy / contracted capacity, *for each individual consumer*

❑ Experimentally, one can determine a curve that fits the ideal tariff that would correspond to each consumer with its UF

   ◆ It has been found that such a curve exists (it describes the behavior of most small and medium consumers), but it should be verified and adjusted for each situation

29

Tariffs according to the UF

❑ Consumers are allowed to choose their tariffs *(the straight lines in the figure)* and they happen to be better off if they choose the one that corresponds to their actual UF

Coste

0   1   UTILIZATION FACTOR

— — — LOW   — · — · MEDIUM ·········· HIGH
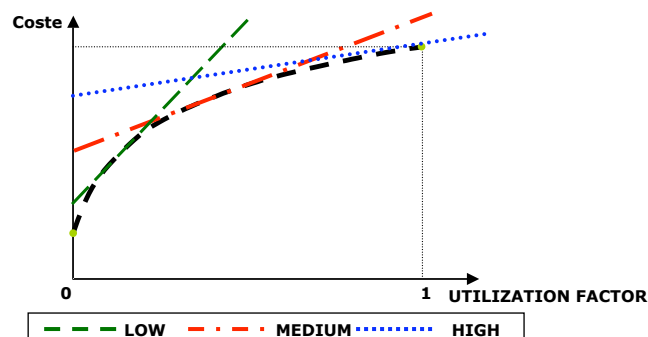
30

Outline

❑General principles

❑**A conceptual model for tariff design**

  ◆Step 1. Specify tariff structure

  ◆**Step 2. Assign each cost component**

  ➤**Generation**

  ➤Network & other costs
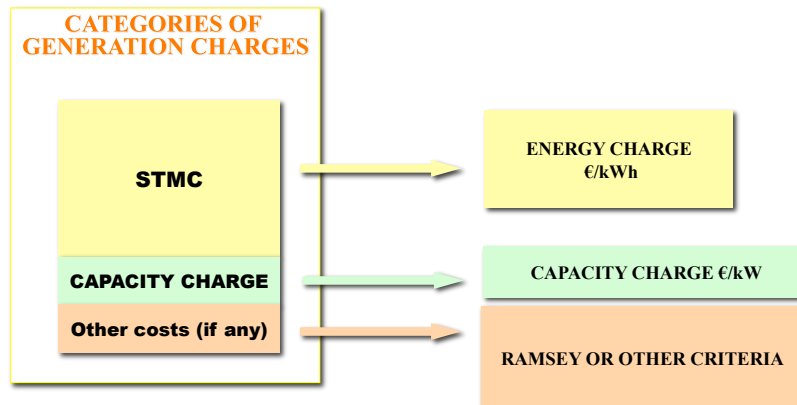
  ◆Step 3. Compute tariffs for end users

31

Allocation of generation costs

❑This tariff component remunerates the activity of generation

❑The preferred approach is based on the **short-term marginal cost** of generation in €/kWh

  ◆Conveys useful & efficient economic signals

  ◆Easier to determine than long-term signals

❑ *(Depending on the adopted approach, if any, to promote security of supply)* Also add a **capacity charge** in €/kW

❑ *(Depending on the regulation)* Add a tariff component in the access tariff to meet **additional commitments** of cost recovery, such as stranded generation costs

32

Allocation of generation costs

❑ The adopted scheme of charges:

CATEGORIES OF GENERATION CHARGES

STMC	→ ENERGY CHARGE €/kWh
CAPACITY CHARGE	→ CAPACITY CHARGE €/kW
Other costs (if any)	→ RAMSEY OR OTHER CRITERIA

33

Allocation of generation costs
With an energy market

❑ The rules of the wholesale energy market guide the definition of the generation charges

◆ STMC: Energy market price €/kWh

   Estimation of the energy market price for the time period of interest, divided into time zones as needed

◆ Capacity charge *(if any)* €/kW

◆ Additional charges *(in case the regulator has authorized some transitory additional charges to recover any stranded generation costs)*

34

Allocation of generation costs
With an energy market

❑ **Difficulties:**

1. **Computation of the short-term marginal costs**

   Even if a wholesale energy market exists, it may not have an explicit mechanism of matching demand & supply bids (e.g. NETA in UK) or the mechanism may be a complex one

   ➤ Then it is needed an explicit computation of the hourly (time zone) energy prices

   ➤ The ex ante computation of tariffs requires an estimation of supply & demand for the time period of interest

35

Allocation of generation costs
With an energy market

2. **Capacity payment**

   Some systems have adopted regulatory measures to promote an adequate level of reliability in the supply of generation to the market

   ➤ In most cases these measures require to pay an extra amount to generators in €/kW of "firm" installed capacity (i.e. that capacity that contributes to the reliability of the system)

   ➤ The design of tariffs requires to find some criterion to allocate these generation costs to consumers

   • According to the contribution of the demand of each time zone to the reliability of the system (probability of loss of load)

36

Allocation of generation costs
With an energy market

3. Additional component

This component is very much dependent on the regulatory framework

➢ In California or Spain, in the initial years after liberalization this corresponded to the stranded generation costs component

➢ Possibilities of allocation of this cost to consumers

- A fixed amount per consumer
- A uniform % on the remaining tariff for each consumer
- Ramsey pricing *(second best efficiency, although it may be considered to be discriminatory)*

➢ Typically this will be a component of the access charge *(see later)*

37

Allocation of generation costs
Without an energy market

❑ Even if there is no wholesale energy market, it is recommended to act in an identical way

❑ It is therefore necessary to address the same three tasks *(where now the three components will be required to cover the cost-of-service)*:

◆ Computation of the expected short term marginal cost of generation

◆ Capacity payment

◆ Revenue reconciliation

38

Outline

❑General principles

❑**A conceptual model for tariff design**

◆Step 1. Specify tariff structure

◆**Step 2. Assign each cost component**

➢Generation

➡ ➢**Network & other costs**

◆Step 3. Compute tariffs for end users

39

Assign (network + other regulated) costs to each time zone

❑These are **access tariffs** to distribution & transmission networks

❑They include the incurred network costs plus other unavoidable regulated charges

❑Charges must recover all regulated costs that can be attributed to each voltage level

❑Charges will be different according to voltage level, consumer type and time zone *(typically there is no geographical differentiation inside a given distribution utility; locational differentiation is sometimes used in transmission)*

40

Considered costs

❑Identify all regulated costs to be considered:
- ◆Total transmission costs
- ◆Total distribution costs
- ◆Some unavoidable commercialization costs
- ◆Costs of institutions *(OM, OS, Regulator)*
- ◆Depending on the country
  - ➢Stranded costs *(generation, typically)*
  - ➢Subsidies to renewable energy sources
  - ➢Other costs (support to nuclear industry, compensations to islands, etc)

41

Network costs

❑ Distinguish between dedicated costs (connection charges, either shallow or deep charges) & common network costs
- ◆ Standard network connection costs
  - ➢ Fixed charge per consumer under normal conditions
  - ➢ Special charges for special requests *(e.g. Large distances)*
- ◆ Common network costs
  - ➢ To be allocated to voltage levels & time zones

42

Summary
Assign common network costs

◆ **Split network costs by voltage level**
◆ **For each voltage level:**
  ➢ Split the network cost into a **capacity** & an **energy** component using principle of cost causality *(use experts' opinion on allocation of responsibilities in network investment)*
  ➢ Split the capacity & the energy cost component into **time zones** *(use experts' opinion on allocation of responsibilities in network investment or just capacity to peak time zone & energy pro rata)*
  ➢ Compute the **per unit cost** of capacity & energy for the network at each **voltage level** & time zone
  ➢ Compute the **per unit cost** of capacity & energy for **each type of consumer & time zone**

45

Assign common network costs to each time zone: Details

A. For each considered voltage level and a given year
  ◆ **Determine the total network cost**
  ◆ **For each time zone h:**
    ➢ Determine the **aggregated load & generation**
    ➢ Determine the **equivalent demand** (see figure)
    ➢ Determine the network **losses**
    ➢ **Split network cost & losses into a total load charge & a total generation charge**
    ➢ Compute **loss factors**, to be used later to
      • modify loads connected at different voltage levels so that they can be compared in the allocation of network costs at a given voltage level
      • modify energy charges so that incurred losses are paid for

46

(clarification note)
How to compute & use loss factors?

For each voltage level

- ◆ Start from losses Lvt in voltage level v and time zone h

- ◆ Allocate Lvh between generation and aggregated demand (connected at v plus equivalent from lower levels) in v

- ◆ Compute the loss factor fvh for demand

$$Lvh = fvh \cdot (\text{aggregated demand in v})$$

- ◆ Move the aggregated demand in v to the next upper level

$$(1 + fvh) \cdot (\text{aggregated demand in v})$$

and so on, until the transmission level is reached

47

Assign common network costs to each time zone: Details

B. Split the total network cost of a voltage level into a capacity & an energy component *(principle of cost causality)*

- ◆ Capacity charge ($/kW)
  - ➢ Minimum fraction of the network that is needed to meet the peak load under normal & any specified contingency conditions

- ◆ Energy charge ($/kWh)
  - ➢ accounts for the fraction of the network that is needed to optimize the equilibrium of investment vs. losses and non-served energy costs
  - ➢ energy consumption gives information on peak demand & energy profile for consumers with only-energy metering & a contract for maximum capacity

48

Assign common network costs to each time zone: Details

C. Allocate the capacity & energy cost components of each voltage level to each time zone

- ◆ Capacity charge ($/kW):
  - ➤ Allocate the capacity fraction of the network costs of a voltage level v to the time zone with peak demand
- ◆ Energy charge ($/kWh):
  - ➤ Allocate to the time zones pro rata to the energy demand for each zone *(other less linear criteria may be feasible)*

Assign common network costs to each time zone: Details

D. Compute the per unit cost of capacity and energy for the network at each voltage level & time zone

- ◆ **Per unit capacity charge:** Divide the capacity charge for the network at that voltage level by the peak equivalent demand for that level *(same for other non-peak time zones, if necessary)*

- ◆ **Per unit energy charge:** Divide the energy charge for the network at that voltage level and time zone by the energy corresponding to that time zone

Assign common network costs to each time zone: Details

E. **Compute the per unit cost of capacity & energy for *each type of consumer* & time zone**

  ◆ It is assumed that each consumer only uses the network at the voltage level where it is connected plus all networks at higher voltages

  ◆ **Capacity charge:** Accumulate the per unit capacity charges for all corresponding voltage levels, while taking into account
    ➢ the aggregated load profile of the consumer type
    ➢ the effect of losses when moving between voltage levels

  ◆ **Energy charge:** Accumulate the per unit energy charges for all corresponding voltage levels, while taking into account
    ➢ the aggregated load profile of the consumer type
    ➢ the effect of losses when moving between voltage levels

51

Allocation of other regulated costs

OTHER COSTS

❑ Commercialization costs
  ◆ These are regulated costs *(meant for regulated tariffs)*
  ◆ Recommended: Annual charge per consumer of each type

❑ The cost of institutions *(SO, MO, Regulator)*
  ◆ Recommended: % on final tariffs
    ➢ For OM & OS some fraction may depend on the volume of activity

❑ Other costs
  ◆ Ramsey-like pricing may be an interesting option
    ➢ However, this requires some crude estimation of the elasticities of consumers

52

Outline

❑General principles

◆Regulatory principles

◆Structure

◆Integral & access tariffs

❑**A conceptual model for tariff design**

◆Step 1. Specify tariff structure

◆Step 2. Assign each cost component

➡️ ◆**Step 3. Compute tariffs for end users**

53

Computation of end-use tariffs

A. Per unit charges for each consumer type are determined by adding the fixed, energy & capacity components separately for each component of the total cost & each time zone

◆ **Network costs**
  ➢ Energy
  ➢ Capacity

◆ **Generation costs**
  ➢ Energy
  ➢ Capacity

◆ **Commercialization costs**

◆ **Other costs**

54

Computation of end-use tariffs

B. It is necessary to adapt the per unit charges for each consumer type according to its tariff structure

- ◆ Make use of averages or aggregation whenever the tariff structure must be simplified
- ◆ Whenever convenient, extend the tariff structure by making use of utilization factors (in order to avoid cross-subsidies among consumers under the same tariff but with different utilization factors)
  - ➢ Very short utilization factor *(similar to back-up service)*
  - ➢ Short
  - ➢ Intermediate
  - ➢ High

55

END OF PRESENTATION

56

28

ESD.934 / 6.695 / 15.032J / ESD.162 / 6.974 Engineering, Economics and
Regulation of the Electric Power Sector
Spring 2010