

Engineering, Economics & Regulation of the Electric Power Sector

ESD.934, 6.974

Session 15

Module E.4

Electricity transmission: Pricing

Prof. Ignacio J. Pérez-Arriaga

Study material

- L. Olmos, I.J. Pérez-Arriaga, "A comprehensive approach for computation and implementation of efficient electricity transmission network charges", MIT-CEEPR-09-010, July 2009.

Readings

- PJM, "A survey of transmission cost allocation issues, methods and practices", March 2010

Regulation of transmission services

PRICING

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Pricing What is the objective?

- To ensure that the energy prices & the transmission network charges that are levied to the network users
 - ◆ send efficient economic signals
 - in the short-term (for operation decisions)
 - in the long-term (for investment & location decisions)
 - ◆ recover the complete regulated costs of the transmission network
 - ◆ are non discriminatory
 - ◆ are easy to understand & implement, & perceived as fair

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Pricing Principles (1 of 2)

- Efficient transmission charges should be based on “cost causality”
 - ◆ This translates (*remember the rationale for justification of transmission investment*) into
 - allocation to **economic beneficiaries** of the network or
 - allocation to those users who could be considered responsible for the network investmentwhich are really equivalent criteria (*& both difficult to apply in practice*)
- But this criterion is difficult to apply in practice

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Pricing Principles (2 of 2)

- A proxy: some measure of “physical network utilization” could be used instead (*where, when & how much energy is injected or withdrawn, whether actual, potential or estimated*)
 - ◆ & never related to the particular commercial transaction established by the network users since, with well informed & rational agents, network utilization does not depend on commercial transactions
 - ◆ Unfortunately there is no indisputable procedure to measure “physical network utilization”

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Pricing Short-term signals

□ Nodal prices

- ◆ are **energy** prices that internalize the network effects: losses & congestions
- ◆ provide correct economic signals for system operation
- ◆ result in a net surplus, which in practice happens to be insufficient to recover total network costs

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Pricing Long-term signals

- ### □ They are meant to recover the total network costs (*either jointly with nodal prices or, if nodal pricing is not used, by themselves*) → transmission tariffs
- ◆ based on cost causality of network costs as much as possible, or network utilization otherwise
 - ◆ these charges should not be transaction-based
 - ◆ long-term charges (*transmission tariffs*) should try to avoid interference with (distortion of) short-term signals (*nodal prices*)

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Pricing

Other network-related signals

- Network-related locational signals can be also sent in other ways
 - ◆ Information on estimated future network conditions (*congestions, loss factors, transmission charges*)
 - ◆ Location dependent capacity mechanisms
 - Definition of firm capacity may depend on location

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PRICING

Location signals in energy prices

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Location signals in energy prices

Option 1: Nodal prices

Examples: Argentina, New Zealand, most ISOs in the US

- Losses & network constraints are implicitly taken care of
 - ◆ this is very convenient in non well meshed networks, with systematic network constraints
 - ◆ an algorithm is needed → loss of transparency
 - ◆ bilateral physical contracts need some ad hoc solution
- Nodal prices result in a net revenue ($\approx 20\%$) that can be used to partly offset transmission costs →
 - ◆ need for a complementary charge ($\approx 80\%$)
 - ◆ as the complementary charge is so large, the basic network cost allocation problem still remains unsolved

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Location signals in energy prices

Option 2: Zonal prices

- Examples: California & Texas (*both have moved to nodal pricing*), NordPool, Italy
- By default there is a single market price, except when any systematic inter-zone restriction becomes active → zonal prices
 - ◆ Revenues from application of “zonal prices” should be used to partly remunerate network costs
 - ◆ Sporadic network constraints can be solved via redispatch

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Location signals in energy prices

Option 3: Single energy market price

- Examples: England & Wales, Colombia, Sweden, Spain
- Coexistence of a single energy market price & separate short-term signals for losses & constraints
- Separate treatment for these concepts:
 - ◆ energy market price
 - ◆ network cost recovery → transmission tariffs
 - ◆ management of network constraints
 - ◆ network losses

where any net revenues from the schemes that are used to deal with losses or constraints may be applied for partial network cost recovery

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Single energy market price

Dealing with losses (1)

- ◆ Losses can be allocated among generators (L_g) and demand (L_d) so that their respective outputs & loads are modified according to their respective loss factors
 - ◆ *Example:* Consumers in mostly importing areas will be charged for more energy than what they consumed: $d' = d + L_d$.
 - ◆ *Example:* Generators in mostly exporting areas will be paid for less energy than what they produced: $g' = g - L_g$.
- ◆ This scheme should influence the market bids:
 - generator bid price = original bid price $\times g/g'$
 - consumer bid price = original bid price $\times d/d'$

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Single energy market price Dealing with losses (2)

□ Bidding process:

- ◆ Loss factors can be estimated by the ISO
- ◆ Participants use their best information to construct bid prices
- ◆ Market clearing
- ◆ Final settlements are made using ex-post penalty factors based on the resulting dispatch. Previous estimations are ignored
- ◆ Some risk associated to errors in the prediction of the network conditions (usually not very relevant)

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Single energy market price Network congestion management

- ### **□ Several congestion management methods are applicable (see the slides on "access")**
- ◆ Redispatch
 - ◆ Countertrade

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PRICING

Transmission tariffs

(Allocation of network costs: the complementary charge)

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Allocation of network costs Basic guidelines

- Network costs should be fully recovered from charges applied to the network users
- Any network costs that are not recovered via nodal prices or equivalent signals must be assigned via transmission tariffs so that
 - ◆ long-term location signals (*if needed*) are sent (*basically of interest only to new network users or those who might retire*)
 - ◆ distortion of short-term economic efficiency is minimized

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Implementation

How to do it? (1 of 3)

- How to recover the total network costs?
 - ◆ Assign the complementary charge by
 - looking at cost causality of network costs →
 - ideally charge to the economic beneficiaries (remember the drivers of an efficient transmission planning) → guide long-term location decisions of the agents
 - in practice replace "benefit" by "electric usage" if allocation to beneficiaries is too complex
 - charge any remainder while trying to minimize economic distortion → Ramsey-like ideas may help / relative price sensitivity of consumers & producers
 - ◆ & remember
 - charges should never be transaction-based
 - long-term charges should try to avoid interference with (distortion of) short-term signals

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Implementation

How to do it? (2 of 3)

- A basic criterion: Make it simple, unless forced by the network characteristics, such as:
 - ◆ poorly meshed / radial networks with systematic active constraints
 - ◆ need for major & expensive reinforcements, so that cost allocation becomes a contentious issue
 - ◆ multiplicity of connection applications by generators, so that locational signals should be an essential ingredient in efficient siting decisions
 - ◆ There is competition between alternative projects or technologies (e.g. gas by pipe vs. gas by line) so that network charges might decide

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Implementation

How to do it? (3 of 3)

- How to split the network cost among generators & consumers?
 - ◆ “Fundamentalist” reasoning
 - “Generators need the network to sell their product”
 - “Consumers need the network to access the product”lacks economic fundament
 - ◆ Use “cost causality” as much as reasonably possible
 - at least try that the distortion of economic efficiency is minimized
 - Ramsey pricing (assign costs in inverse proportion to price elasticity) → Note that, in a competitive electricity market, generation is more price elastic than most of the consumers

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Transmission tariffs

Approaches used in practice

- Beneficiaries
 - ◆ Try to evaluate the economic benefit that each network user obtains from the existence of each individual transmission facility and allocate its cost pro-rata to each user
- Responsibility in investment
 - ◆ Try to evaluate the extra investment cost that each network user imposes on to the existing network, besides its dedicated (shallow) connection
- Network utilization
 - ◆ Try to evaluate the power flow that each network user causes (marginally or as average) on each transmission facility and allocate its cost pro-rata to each user
- Postage stamp
- Plus interesting ideas not yet used: e.g. Aumann-Shapley

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Transmission tariffs

Option 1: Beneficiaries

- ❑ Evaluate the economic benefit that each network user obtains from the existence of each individual transmission facility and allocate its cost pro-rata to each user
 - ◆ When a facility meets the golden investment rule, the aggregated benefits exceed its cost → *this method minimizes distortion in long term decisions of users & promotes participation in coalitions to build lines*
- ❑ It inspired the overall regulatory approach in Argentina & it has become increasingly popular because of its sound economic basis & superficial “political” appeal
- ❑ But it faces insurmountable implementation difficulties in general (*except perhaps only for new investments*)

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detail

The notion of benefit

- ❑ Benefit: “the economic impact that, for a network user, derives from the existence of a network installation (*or a group of them*)”
 - ◆ The absolute benefit of an agent in the market should **not** be considered to be equal to the benefit that is derived from the existence of a particular network asset
 - ◆ In general, but not always, both generators & consumers have network-derived benefits
 - ◆ Network derived benefits are difficult to determine: electrical use is often used as a proxy; however, in all cases, at least use the benefit as a conceptual guide

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Transmission tariffs

Option 2: Responsibility in investment

- Evaluate the extra investment cost that each network user imposes on to the existing network, besides its dedicated (shallow) connection
- The ICRP (investment cost related pricing) method in UK, & Colombia later, is an example
- It makes sound economic sense; however
 - ◆ all yet proposed evaluation methods are questionable & results depend much on the assumptions
 - ◆ difficulties in allocating 100% of the total cost → resort to Ramsey pricing

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Transmission tariffs

Option 3: Network use

- Evaluate the power flow that each network user causes (marginally or as average) on each transmission facility and allocate its cost pro-rata to each user
- The "areas of influence" method in Chile or Argentina, or the "average participations" in New Zealand, Central America or Australia are examples; the MWxkm method can be also included here
- However
 - ◆ all evaluation methods are questionable
 - ◆ weak economic rationale (although it seems to make engineering sense to many and it is a proxy to benefit)

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Transmission tariffs


Option 4: Postage stamp

- ❑ Simple access charge (usually flat, although it may depend on location according to some easy rule) that allocates 100% of the transmission cost
- ❑ The transmission tariffs in most European countries are based on the postage stamp method
- ❑ Recommended when the network characteristics do not demand more sophistication (*well meshed networks without major pending reinforcements & without multiple competing requests for access*)
- ❑ Cost reflectivity of network charges is achieved here by losses & constraint management signals only, not in the allocation of network costs

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END OF PRESENTATION

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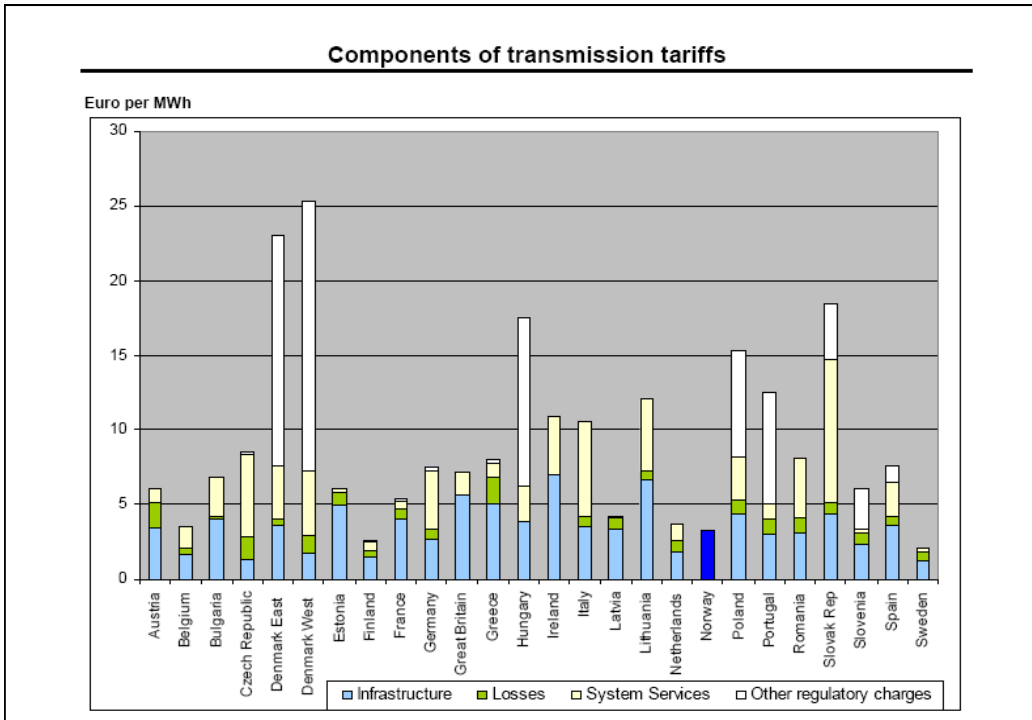
Annex 1

Experiences with transmission tariffs (EU)

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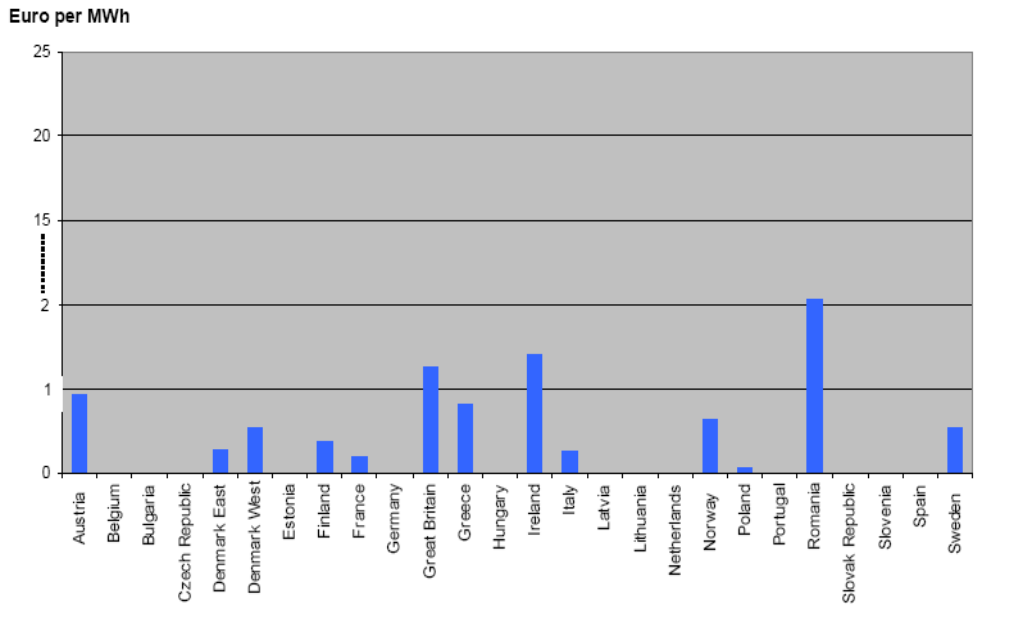


The components of the cost in the
transmission tariffs in EU differ widely ...

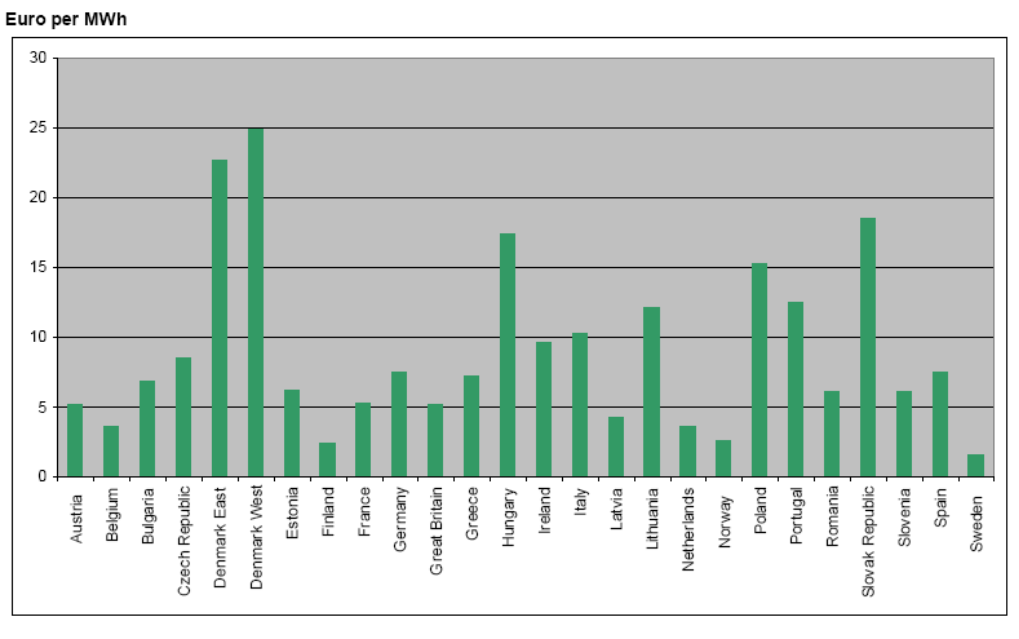


... as well as the structure of the tariffs themselves...

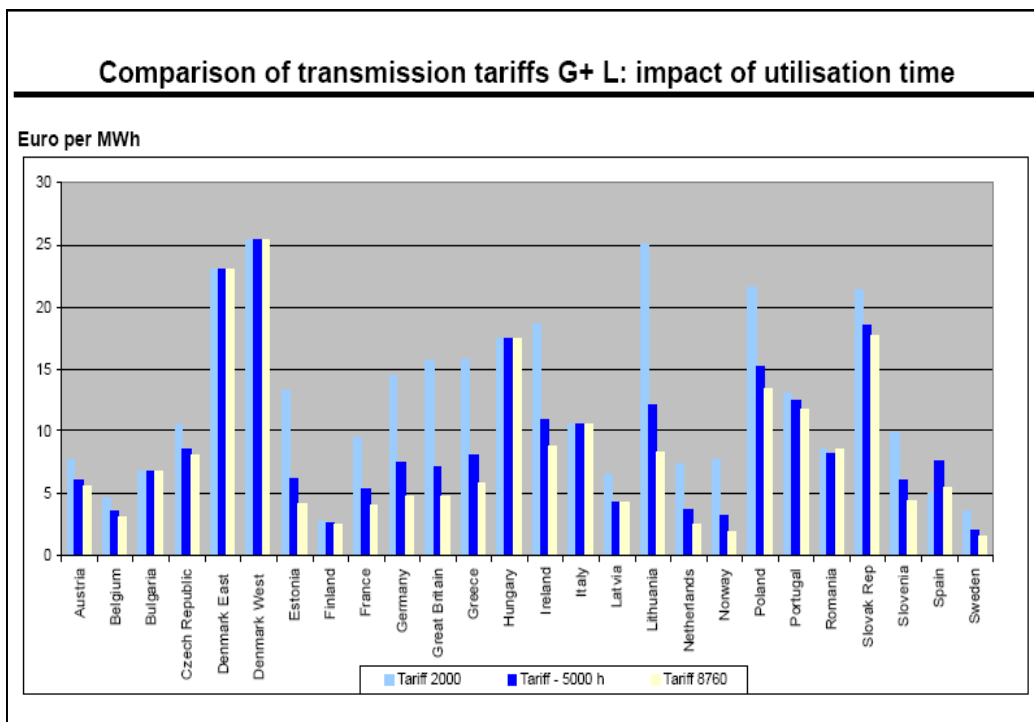
Range of G components paid in 2007 by producers across Europe



Range of L components paid in 2007 by load across Europe

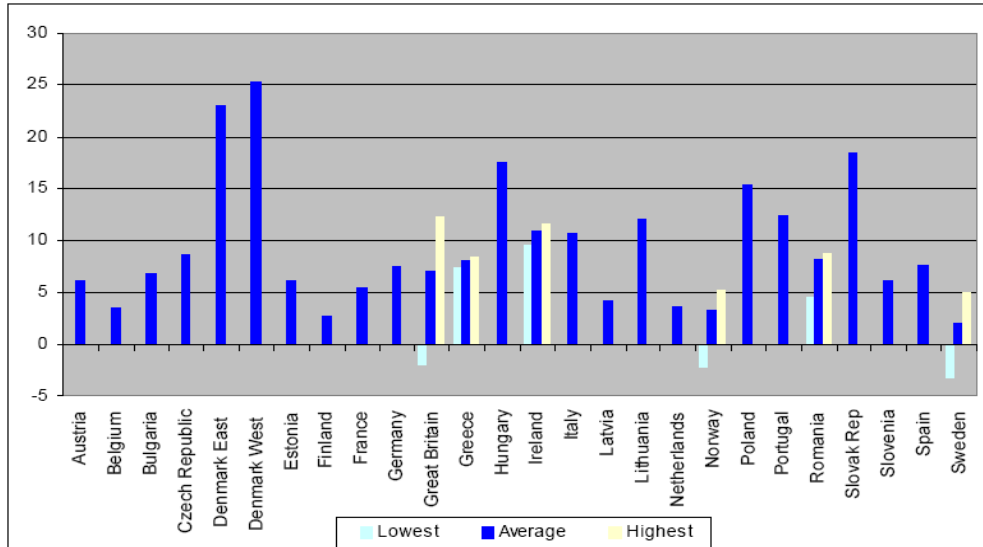


... and the final numerical values of the tariffs, without a convincing explanation, plus the diversity in the factors that are taken into account (*location, utilization time*)



Comparison of transmission tariffs G+ L: impact of location

Euro per MWh



Annex 2 DETAIL ON THE METHOD OF AVERAGE PARTICIPATIONS (AP)

Underlying assumption behind the method Average participations (AP)

- Accepting the **technical impossibility to assign line flows unambiguously to sinks or sources**, it is assumed that this responsibility can be simply obtained by tracking each flow upstream & downstream following the same paths & branching proportions that exist in the actual flows provided by ETSO
 - ◆ By construction, the use of each line is assigned 50/50 to demand & generation, although this proportion may be easily modified afterwards if the user of the algorithm has a good reason to do so

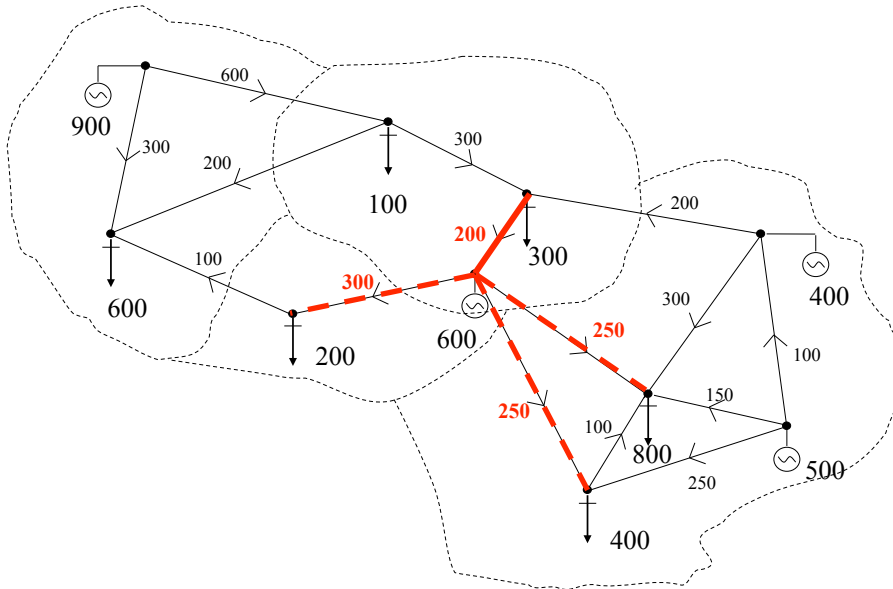
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Why is not possible to assign the flows to sources & sinks?

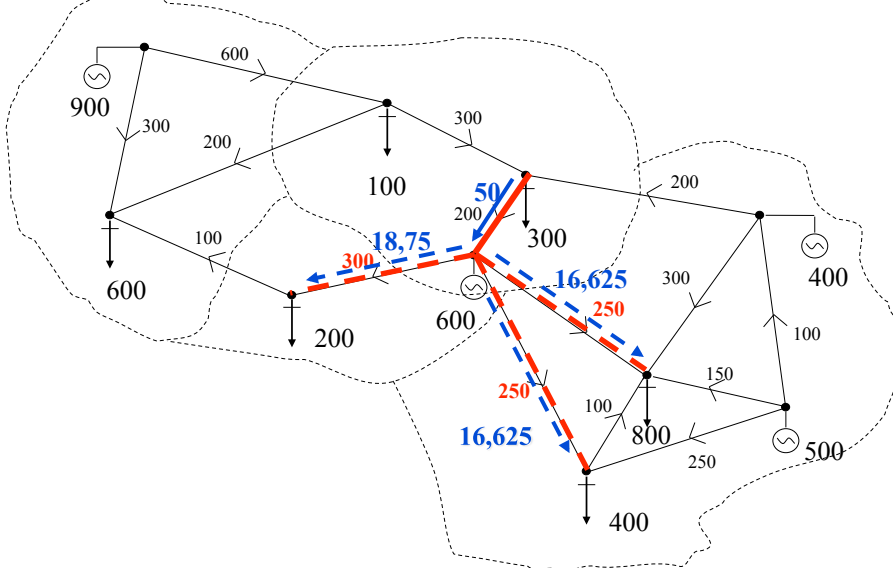
- Load flows & circuit theory are just a convenient approximation to **electromagnetic field theory**, which is "as close as we can get" to explaining the flow of electromagnetic energy:
 - ◆ Energy flow is guided by lines & takes place in the broad space around them (**outside the lines**)
 - ◆ **Energy flow establishes at the speed of light & is the result of the joint & inseparable contribution of all sources & sinks** acting together & interacting with one another → it is not possible to attribute a piece of energy flow to a particular generator or load
 - Probably the most reasonable thing to say is that any fraction of the flow that is guided by a line, branches in the same proportion as the total flow in the line (*this is the basic assumption of AP*)

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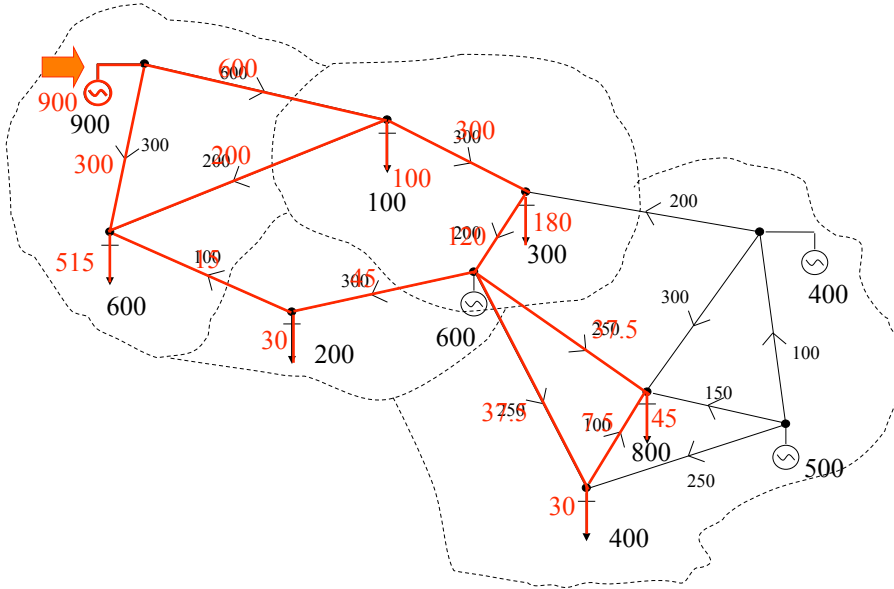
The basic assumption behind AP: If an energy flow of 200MW branches as 300, 250 & 250 MW at a node, **then...**



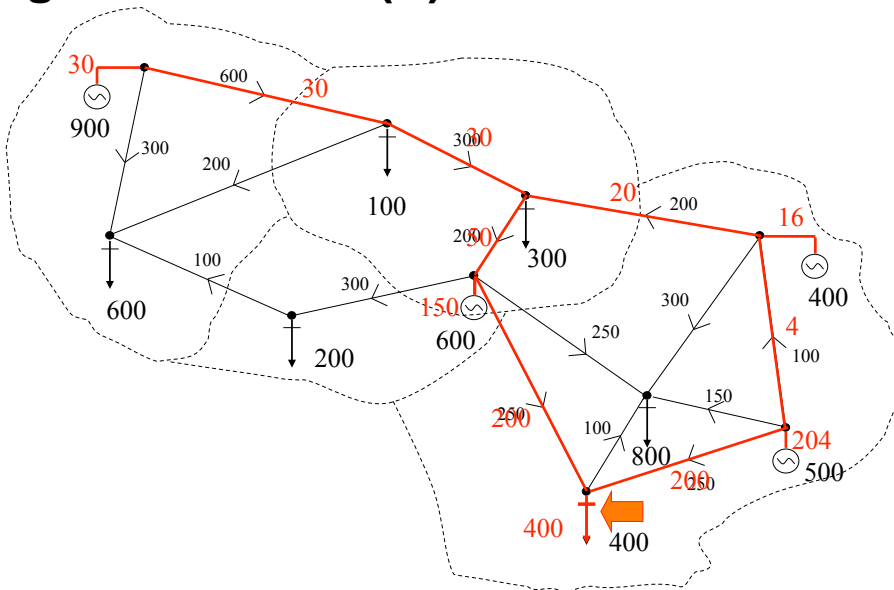
... then a flow of 50 MW in this same line, which I want to track downstream, will branch pro rata to 300, 250 & 250 in the same lines that meet at the node



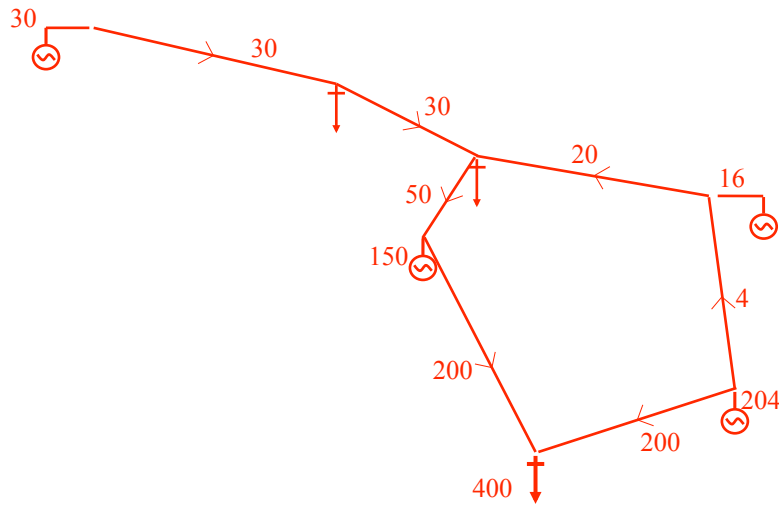
This is how the “average participations” algorithm works (I)



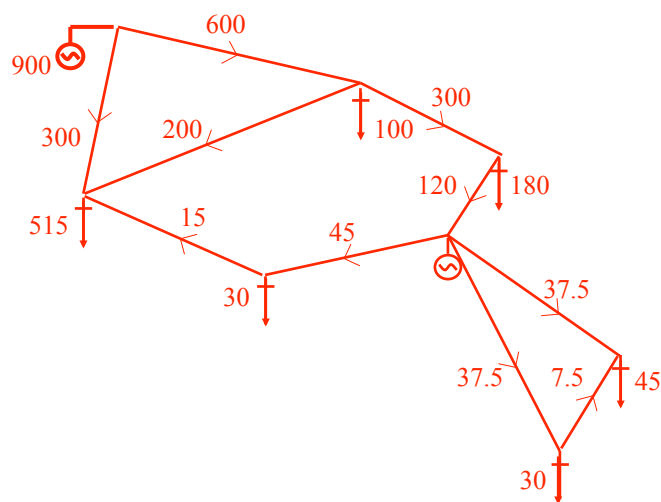
This is how the “average participations” algorithm works (II)



Flow pattern that feeds a load node



Flow pattern fed by a generation node



Is AP a reasonable method?

- It **tracks the flows as they are**, with no other spurious assumptions: If the complete flow (200 MW) branches as it does, a fraction of it (50 MW) will branch in the same proportion
- Do the flows die **too soon** with AP?
 - ◆ Who has the a priori knowledge to tell how far or close the flows die? They do what they do; AP does not change reality
 - ◆ Some of the actual flows travel far
 - ◆ Some small inconsistencies may happen at micro level, which can be fixed & are irrelevant for ITC

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Is AP a reasonable method?

There is also an economic justification for AP

- If we accept that power in a line only flows in the direction of the actual flows (*this is, we do not think of decomposing actual flows as superposition of many flows going in all directions*), then the transmission charges resulting from the application of AP coincide with the Shapley value for each agent in a cooperative game with good properties in terms of fairness, efficiency & stability
 - ◆ AP & a new cost allocation method named Aumann-Shapley, with strong economic basis, have given very similar numerical results on test cases performed in the Brazilian transmission network

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Session 16
Module E

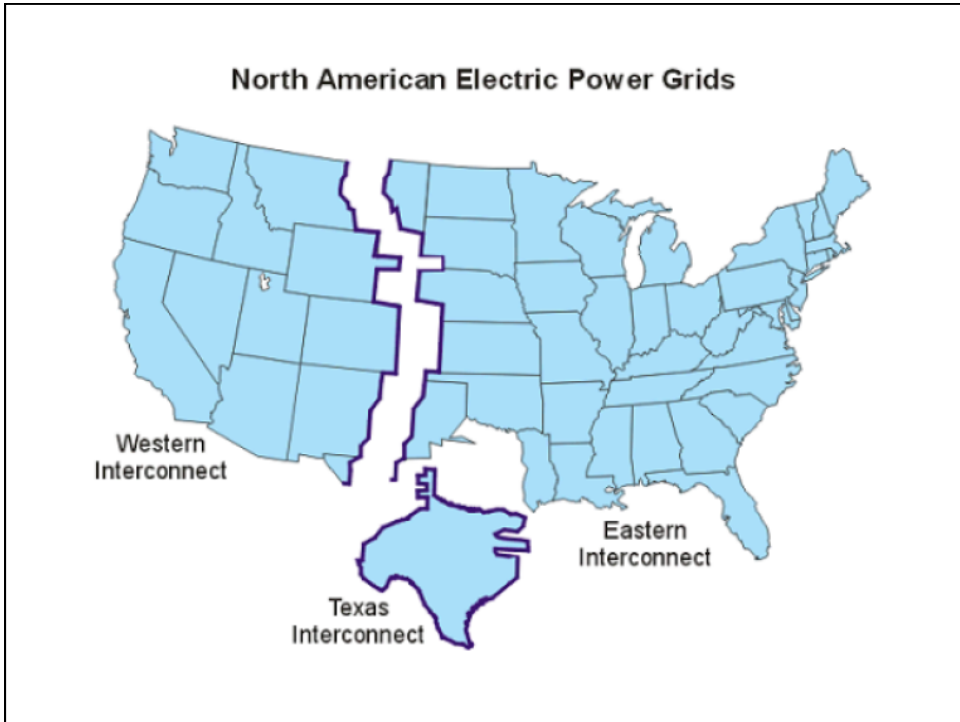
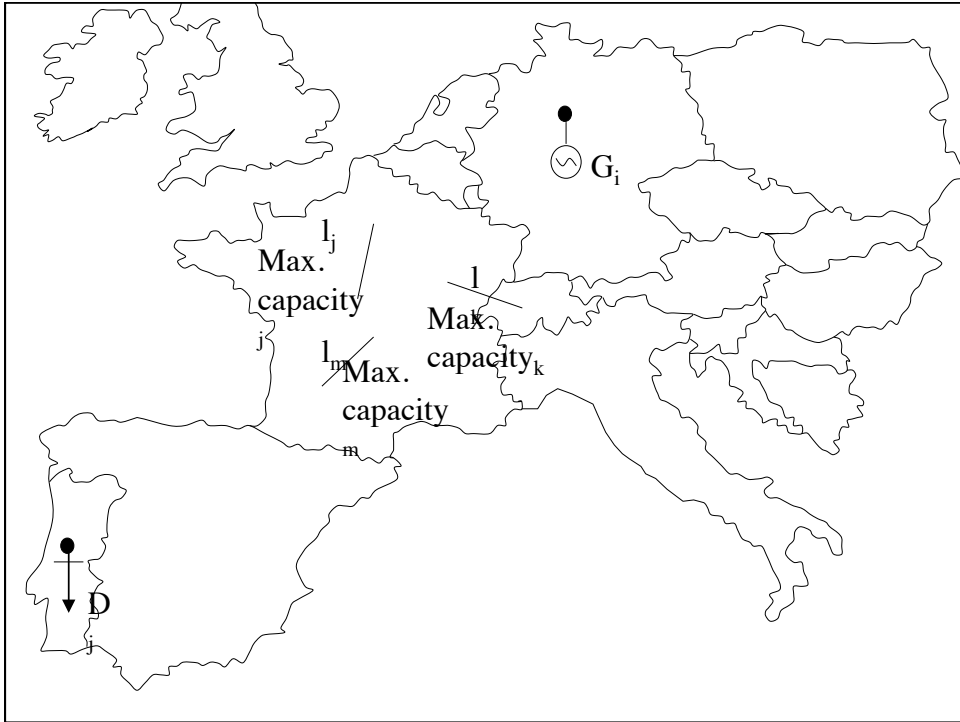
Additional material Formats of contracts

Prof. Ignacio J. Pérez-Arriaga

Bilateral contracts, which format?

- Diversity of formats of bilateral contracts
 - Pure bilateral, OTC (over-the-counter), in organized markets
 - Physical, financial & firm contracts
 - The price of reference
 - Firm transmission rights (FTRs), how much firm are they?
 - Implications on security of supply, physical dispatch, congestion management
- In a wide diversity of contexts (*see next slides*)





CENTRAL AMERICAN ELECTRICITY MARKET

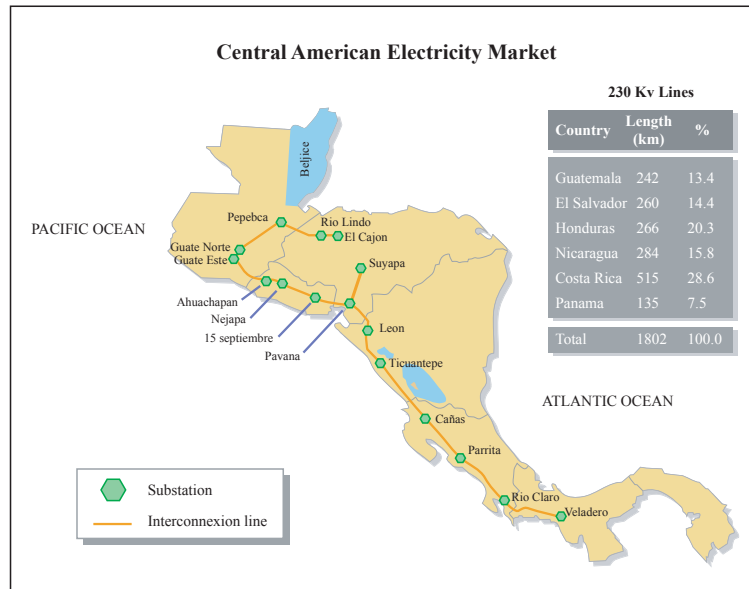


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Basic contracting formats Financial bilateral contracts (1)

A bilateral agreement, or via an organized power exchange, resulting in an economic transaction between two parties that is referenced to a market price (typically the hourly spot price of the daily market)

- Its direct implications are strictly economical, therefore they are ignored in the physical dispatch & they do not have to be reported to the System Operator (SO)
- They do not require physical delivery of the product, this is just an economic transaction



Basic contracting formats

Financial bilateral contracts (2)

- Any legal person can be a party to these contracts, not necessarily a market agent → this increases liquidity
- The price risk in the contract is naturally hedged if the contracted quantities correspond to actual production & demand of the contracting parties
 - Otherwise the risks are large
- There are sometimes difficulties with the definition of the reference price
 - If the price transitorily ceases to exist (e.g. if there is no market clearing price (*this is very unusual*))



Basic contracting formats

Financial bilateral contracts (3)

- Several possible formats:
 - CfDs, options, etc.
- The price of reference could be
 - The hourly energy price in a day ahead market (*most usual*)
 - The difference in nodal prices between two specified nodes
 - A basket of energy prices in different markets
- The parties to these contracts, generators or consumers, can also buy or sell electricity in any organized short-term markets that might exist, at the corresponding prices, with total independence of the financial bilateral contracts



Basic contracting formats

Firm bilateral contracts (1)

Bilateral agreements, typically, with the following implications for the contracting parties:

1. The supply **price** is established in the contract, whose terms are confidential
 - The meaning of the agreed quantity Q depends of the type of contract (*see later*)
 - The price may include an energy component P_e (€/MWh) and also a capacity component P_p (€/MW) to remunerate firmness
 - The consuming entity will pay & the generator will receive the contract price, with independence of the local energy price (& capacity price, if any) in their respective markets, although they will be subject to any specified charges/credits as market participants
 - difference in the corresponding nodal prices
 - deviations with respect to declared contracted quantities
 - charges or credits for use or provision of ancillary services



Basic contracting formats

Firm bilateral contracts (2)

2. A physical bilateral contract has the commitment of **physical delivery** of the product; therefore if the generator fails (or prefers not to produce) the generator must provide back-up generation or buy the electricity locally

- The price & format of the local acquisition of energy (if any) depend on the characteristics of the local electricity market where it has to be purchased, for instance
 - day ahead energy market, followed by intraday markets in a power exchange (as in Spain)
 - day ahead energy market in a power exchange or balancing market closer to real time (as in the UK)
- Note that in the *financial* contracts the agreed reference price may be different from any actual price in any market (*e.g. it could be a basket of prices*)



Basic contracting formats

Firm bilateral contracts (3)

3. The consumer party has **priority** in the physical supply (*complete guarantee of supply is impossible*), under conditions of scarcity, with respect to similar consumers without firm contracts. *But the contract has to meet the following conditions:*
- The contracted generation capacity has to meet any conditions that are required at domestic or regional level to **qualify as firm capacity**; at least:
 - the capacity can only be committed once
 - the capacity cannot be taken back (in international transactions) by the country of origin



Basic contracting formats

Firm bilateral contracts (4)

(*continuation*)

- in case of scheduled unavailability of the generator during the time of the contract, there must be a committed back-up capacity
- Other firmness conditions are also possible
- There must be **sufficient available network capacity** so that the contracted transaction is physically possible
 - If necessary, satisfaction of this condition may require that the contracting parties purchase some amount of firm transmission rights (FTRs) between the nodes (or the zones) where the two parties are physically located
 - Any concerned system operators (one or more) have to establish the mechanisms to allocate the FTRs & verify that this condition is met



Basic contracting formats

Firm bilateral contracts (5)

- 4 Physical bilateral contracts must be **declared** to the SO & they have physical implications
- Self dispatch by the generator & consumer, who do not need to go to any organized market
 - optionally, if there is no scarcity problem in the local supply to the consumer, the generator may purchase the energy at the consumer location
 - Since the contract has associated FTRs, there is no need to resort to any short-term congestion management mechanism
 - When buyer & seller belong to different “control areas” & there is no common coordinated dispatch, the contract has to be accounted for by the respective OS to establish the import / export programs



“Firm” bilateral contracts

“Firm” transmission rights (1)

- If FTRs are not really “firm” (*just financial*)
 - FTRs are “contracts for differences” with a quantity Q and a reference price
$$\text{nodal price } k - \text{nodal price } j$$
 - The FTRs provide a hedge for the contracted amount Q against the actual price difference between nodes k & j
 - Every hour the FTR is paid
$$Q \times (\text{nodal price } k - \text{nodal price } j)$$
- ➔ If the parties of the contract are trading Q during that hour, they can do it at the agreed price, ignoring the value of the nodal prices (*however, they should not ignore grandma’s theorem*)



“Firm” bilateral contracts

“Firm” transmission rights (2)

- FTRs have to be purchased
 - The right price of an FTR for a quantity Q & a duration T between nodes k & j is the expected average value of (nodal price k – nodal price j) during the period T , multiplied by $Q.T$
 - The income that could be obtained from selling FTRs for all the lines in a well developed network is expected to be much lower than the cost of that network (about 20% of its cost)
 - In specific cases the FTRs could pay for the costs of a line, or more, while any existing systematic congestion situation lasts
 - “simultaneous feasibility” implying “revenue adequacy” is needed to ensure the counterparty (the ISO) does not incur in unacceptable risks



Firm bilateral contracts

Firm transmission rights (1)

- If FTRs are really “firm”
 - They are not limited to hedge financially against the uncertainty in the difference of nodal prices of the consumer & the generator
 - They also guarantee that the contract has enough network capacity available between the two considered nodes
 - Then the concerned SO(s) have to verify the simultaneous feasibility of all awarded FTRs
 - Note that “simultaneous feasibility” implies “revenue adequacy” (i.e. the counterparty of all the FTRs, typically the OS, has no risk in collecting congestion rents to pay for the FTRs if the network operates under normal conditions)



Firm bilateral contracts

Firm transmission rights (2)

- The “truly firm” FTRs actually contain two different products, each one with a different economic value
 - Financial hedging with respect to the difference in the local nodal prices of the buyer & seller (*this is all that the purely financial FTRs provide*)
 - Allow buyer & seller to sign a firm bilateral contract so that the seller contributes truly firm guarantee of supply to the buyer
 - this second service also has an economic value by itself



Firm bilateral contracts

Discussion (1)

- The firmness requirement
 - It is not enough the “obligation” of physical delivery at the consumer’s node; it is also required to have the means to meet this commitment
 - sufficient firm generation capacity that is available when needed
 - sufficient dedicated network capacity to physically deliver the contracted amount
 - Otherwise, the consumer has contracted an economic compensation in case there is scarcity of supply, but not an enhanced guarantee of supply
 - Some regulations require that all consumers are covered with firm contracts



Firm bilateral contracts

Discussion (2)

- Under normal conditions, when there is no deficit of supply to meet the demand that the consumer has contracted
 - The generator may prefer to be physically replaced by another generator (without network limitations) or to buy the electricity locally by the consumer location, instead of producing it
 - This is economically efficient & should be encouraged
- Under scarcity conditions by the consumer's location, the local purchase is not possible & only a firm contract guarantees the supply (*while the conditions that make the contract firm hold*)



Basic contracting formats

Physical bilateral contracts (1)

This term has been used with incomplete versions of bilateral firm contracts, which always include the condition of physical delivery by the location of the consumer

What defines these contracts?

- The commitment of physical delivery
 - with electricity produced by the contracted generator or by any other unit
 - or with local energy by the consumer, if available
 - the contract is declared to the SO & there is no need to bid into a power exchange
- The economic settlement, similar to financial or firm contracts



Basic contracting formats

Physical bilateral contracts (2)

What is missing in these contracts?

- (typically) Firm network rights, in case the available local supply for the consumer party is insufficient
- Firmness in generation capacity (or authorization to export, in case of emergency in the country where the generator is located, in an international context)



Physical bilateral contracts

Discussion

- **Physical** bilateral contracts are riskier than **firm** bilateral contracts
 - *For the seller:* since he will have to buy energy at the consumer local price if there is lack of network capacity or generator availability
 - *For the buyer:* since the probability of loss of supply is higher (even if there is an economic compensation)
- Physical contracts must be declared & have the same physical obligations than firm contracts
 - And (depending of the specific regulation) without firm transmission rights it may be necessary to enter in the short-term mechanisms of network congestion management



Case example: Spain

The Spanish physical bilateral contracts

- Required: physical delivery; declaration to the SO; deviations of actual production & consumption must be solved by the contracting parties in short-term markets (*intraday or deviations markets*)
- FTRs
 - are not required for domestic transactions & generators participate (as any other generator) in the mechanism of congestion management
 - must be obtained in ad hoc auctions for transactions across the French border
- Do not provide any additional guarantee of supply



Thank you for your
attention



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