Engineering, Economics & Regulation of the Electric Power Sector

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Session 14.B
Module E.2

Electricity transmission: Investment

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Regulation of transmission services

INVESTMENT

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Readings

- F.F Wu, F.L. Zhengb, F.S. Wen, "Transmission investment and expansion planning in a restructured electricity market", Energy 31 (2006) 954–966.

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Investment
Which is the objective?

- To ensure that all transmission facilities that are "justified", i.e., meet a prescribed social welfare efficiency criterion (which must account both for economic & quality of supply considerations) are
  - built at optimal times
  - properly operated & maintained

  at minimum cost

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The "regulatory test"
What is a "justified" investment?

- Investment optimality according to **traditional regulation**:

"Invest in network assets only while the additional network investment cost is still smaller than the additional saving in system operation costs (generation costs, loss of supply)"

- This definition is consistent with the one adequate for a **context of competition**:

"Invest so that the net aggregated benefits (once network charges are included) of all network users (i.e. generators & consumers) are maximized"

- *Technical reliability rules have to be met in any case, although it is preferable that they are incorporated into the cost / benefit function*

The "golden rule" in both centralized & competitive frameworks (1)

- Traditional framework: Maximize global social welfare

  Max {U(D) - FG - VG - CT} (1)

  U(D): utility for the demand D

  FG: generation fixed costs

  VG: generation variable costs

  CT: transmission total costs

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The "golden rule" in both centralized & competitive frameworks (2)

- Open market framework:

  PD = IG + CT (2)

  PD: payments by consumers (at wholesale level)

  IG: revenues of generators *(once they have paid their transmission charges)*

  CT = IVT + CCT (optionally) (3)

  IVT: "variable" transmission revenues (from application of nodal energy prices to consumers & generators)

  CCT: complementary charge (assuming that transmission is regulated so that its total costs are fully recovered)

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The "golden rule" in both centralized & competitive frameworks (3)

- Open market framework (continuation):

  Rearranging equation (2):

  PD - IG - CT = 0,

  which can be introduced in (1):

  Max {(U(D) - PD) + (IG + CT) - FG - VG - CT}

  & then

  Max {(U(D) - PD) + (IG - FG - VG)} =

  = Max {net benefit of consumers + net benefit of generators}

  as we wanted to prove

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➔ A useful property

- An economically justified network investment under traditional network expansion rules

  network investment cost < savings in operation costs

  will increase the net benefit of

  Generators: income from nodal prices – operation costs – network charges

  Consumers: utility – cost of purchasing electricity – network charges

  if the residual network cost is allocated pro rata of the economic benefits of each network user

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The "regulatory test" in practice

- A fully convincing "regulatory test" is missing in practice
  - to verify that a proposed investment is justified or even that it is the "optimal" one within a set of proposed network reinforcement options
  - the current predominant criterion in Europe & most of US is to comply with prescribed security criteria *(some countries have mandatory "Grid Codes")* & to eliminate network bottlenecks
- Some countries specifically include the criterion of economic efficiency, but it is not clear how this is applied *(or if it is actually applied)*

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Physical components for the transmission function (1)

- Transmission lines
  - Overhead lines & underground cables (AC & DC)
- Elements for connexion, voltage transformation & operation
  - Bus bars
  - Transformers
  - Phase-shifters
  - Breakers
  - Disconnect switches
  - Insulators

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Physical components for the transmission function (2)

- Protection components
  - Automatic breakers
  - Lightning arresters
  - Protection relays
- Metering & control components
  - Voltage & current transformers
  - Telemetering & telecontrol
- Reactive power control
  - Capacitors
  - Reactances
  - SVCs (Static voltage compensators)
  - FACTS, in general

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Investment
Nature of transmission costs

Actual transmission network costs

- Infrastructure costs
  - investment capital costs
  - operation & maintenance costs

Costs incurred because of the existence of the network

- Ohmic losses (generation costs)
- Costs of redispatch that are incurred to eliminate violations of transmission constraints (generation costs)
- Some of the costs of ancillary services
  - reactive power / operating reserves / black start capability

System Operation & transmission are different activities (although sometimes they are performed by the same firm)

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ACRONYMS OF TECHNOLOGIES

FACTS: Flexible Alternating Current Transmission System
FSC: Fixed Series Capacitor
GIL: Gas Insulated Line
HTC: High Temperature Conductor
HTS: High Temperature Superconductor
HVDC: High Voltage Direct Current
OHL: Overhead Line
PMU: Phasor Measurement Unit
PST: Phase Shifting Transformer
SMES: Superconducting Magnetic Energy Storage
SSSC: Static Synchronous Series Compensator
STATCON: Static Condenser
SVC: Static VAR Compensator
TCSC: Thyristor Controlled Series Compensator
UPFC: Unified Power Flow Controller
WACS: Wide Area Control System
WAMS: Wide Area Monitoring System
XLPE: Cross-linked Polyethylene

Transmission costs

(a sample, based on regulated standard costs in Spain, 2002)

- Fixed costs of network facilities *(M stands for "million")*
  - Lines & substations
    - 400 kV 2 Circuit Duplex: 0,288 M€/km
    - 400 kV 1 Circuit Duplex: 0,182 M€/km
    - 220 kV 2 Circuit 0,168 M€/km
    - 220 kV 1 Circuit 0,108 M€/km
    - Substations: 1.8 M€/bay 400 kV
    - Control center: about 4.8 M€
- Operation & maintenance costs
    - 400 kV 3.350 €/circuit/km/year
    - 220 kV 1.940 €/circuit/km/year

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Transmission vs. total costs

(case example: Spain)

- Total regulated transmission costs in 2002:

  582 M€

  347 M€ for REE

  235 M€ for the other transmission owners
- Total electricity supply cost 12000 M€

→ In this case transmission costs amount to less than 5% of total electricity costs

However, in some countries the percentage may reach up to 20%

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Determination of transmission network costs

- Dilemma: Remunerate according to the actual incurred costs or trying to reflect the current marginal investment costs
- Answer depends on who is really responsible for the development of the network
  - *If the transmission firm is **"active"**, then the remuneration must refer to an efficient & well adapted network & economic incentives should depend on the actual contribution to quality of supply, losses & congestion costs, i.e. "performance"*
  - *If the transmission firm is **"passive"**, then the remuneration must refer to the actual network & incentives must just depend on the availability of the network equipment (*)*
- Specific regulation is needed for network assets that are used for non-electrical activities

(*) Some additional "mild" incentives can make sense

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Determination of transmission costs Investment costs

- Alternatives of evaluation of the **"rate base"**
  - From the present market value (potential to generate income): it happens to depend on regulated tariffs
  - From the historic (accounting) cost (ignores technological change, but it matches incurred costs with revenues)
  - From some "replacement value"
    - "depreciated replacement cost, DRC": present cost of the assets that today would provide the same service as the existing assets
    - "optimized depreciated replacement cost, ODRC": present cost of the assets of an optimal network for the present needs
    - "optimized deprival value, ODV": minimum loss that a business would suffer if it were deprived of the asset = min{market value, ODRC}
- The rate of return on capital
  - Weighted average of debt and equity, each one according to its rate of return according to its risk

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Determination of transmission costs (cont.)

- Costs of O&M / management costs
  - percentage (after benchmarking with comparable efficient utilities) of the rate base
- Particular case: The cost of new investments
  - Preferable: assign by auction ➔ pay the winner bid
  - If facility is built by coalition of users just for their own use ➔ regulated value is not needed
  - In general use standard costs as guidance

Alternative approaches to regulation of transmission investment

Investment in new facilities
Approaches

1 System Operator proposes reinforcement plan, to be authorized by regulator. Construction of lines:
   A. Compulsory (all lines) & assigned by competitive bidding or to incumbent
   B. Non compulsory for some (all) lines & left to risk investors to build & negotiate remuneration with network users or regulator

2 A private company is awarded the transmission license and is regulated as a monopoly: subject to grid code; remuneration based on some price control scheme (e.g. RPI-X)

3 Coalitions of network users proposes reinforcements, to be authorized by regulator; regulated remuneration of total costs; construction is assigned by competitive bidding

4 Risk investments: same as above, but coalition bears total costs & regulated remuneration covers partial costs

5 Merchant lines (remuneration based on transmission market value)

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Investment in new network facilities
Approaches *(comments)*

1 **SO + Regulator:** (A) May result in overinvestment if regulator fails to set limits in the authorization process & (B) underinvestment if risk investors do not show up

2 **Private licensed company:** May result in underinvestment unless very careful incentive schemes are implemented

3 **Coalitions of network users:** Only lines with clear beneficiaries will be built. May be a complement to 1

4 **Risk investments:** Same as 3, but more acute. Good to promote investment in underdeveloped networks

5 **Merchant lines:** Cannot be trusted to develop a sound network, since transmission revenues from nodal prices in a well developed network will grossly under recover transmission costs. May be a complement to 1 or 2

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Option 1.A
System Operator + Regulator

- Regularly, the System Operator must propose a plan for reinforcements of the transmission network
  - after taking into consideration (justified) any proposals made by the network users
- Regulatory authorities approve the plan & authorize construction of individual new facilities
- Construction, operation & maintenance of each facility are allocated in a competitive auction
  - pay as bid to winner
  - limited duration of contract; auction for the next period?
  - set availability targets for each facility & penalties (credits) according to the actual performance
- May be complemented by options 3, 4 & 5

Option 1.B
System Operator + Regulator

- Regularly, the System Operator must propose a plan for reinforcements of the transmission network
  - after taking into consideration (justified) any proposals made by the network users
- Regulatory authorities approve the plan & authorize construction of individual new facilities
- Construction, operation & maintenance as in 1.A except for some lines that are left to risk investors
  - who can negotiate remuneration & other terms of contract with potential beneficiaries of the line or with regulator
- Concern: "justified" lines may not be built

Option 2: Private firm & global regulated remuneration

- A private company is awarded the transmission license and regulated as a monopoly
  - Must follow prescribed design requirements (grid code)
  - Incentives to meet performance targets (warning: separate clearly from incentives to System Operator)
  - Global remuneration (RPI-X) for the complete network, while taking into account
    - actual new investments
    - economic lives & depreciation of existing investments
    - economic health of transmission company
    - expected efficiency improvements
- Concern: incentives to under-invest. It is more difficult to estimate the costs for the period than to approve a plan & pay for the facilities actually built

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Option 3
Users have the initiative (A & B)

- Initiative of proposal of network reinforcements corresponds to coalitions of network users
  - OPTION A: coalition builds & pays the reinforcement, which needs authorization from regulator
  - OPTION B: after a quasi-judiciary process (coalitions pro & against, evaluation by system operator) regulator decides whether reinforcement is justified or not.

    If justified, it is built under competitive bidding
    - pay as bid to winner
    - limited duration of license; auction for the next period
    - set availability targets & penalties (credits) according to performance
    - charge cost to all users with general allocation method

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Option 4
Users have the initiative (C)

- OPTION C: risk investments
  Quasi-judicial process as in option B
  If the reinforcement is found justified:
  - the proprietary coalition is selected (a specific auction procedure is followed)
  - assign construction by competitive bidding
  - apply regulated tariffs (attenuated, according to the line utilization) to all network users
  - financial rights on the congestion rents of the reinforcement ("firm transmission rights") are given to its owners

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Option 5
Merchant lines

- Basic idea: Regulate the transmission activity as any other competitive business ➔ merchant lines
  - Remuneration comes from congestion rents
    - Network capacity may even be bid in a short-term market (possible with DC lines)
  - Firm Transmission Rights (FTRs), may be seen not only as a risk hedging mechanism, but also as an incentive for investment
- ***Difficulties:***
  - insufficiency (in general) of market driven revenues
  - high exposure to risk
  - reliability lines
  - potential for market power abuse

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Session 15
Module E.3

Electricity transmission: Access

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Study material

- Transpower New Zealand, "Financial transmission rights", 2001 <An excellent tutorial text>
- For another excellent, but more advanced text (not required): "Integrating European Electricity Markets", 2009, go to

http://www.iefe.unibocconi.it

Readings

- ETSO & Europex, "Development & implementation of a coordinated model for regional & inter-regional congestion management", 2008

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Regulation of transmission services

ACCESS

Part of the material for this module was originally compiled by Alberto Pototschnig (Energy Markets International & advisor to the Florence School of Regulation, FSR) in his courses at the FSR

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Access
What is the objective?

- To ensure nondiscriminatory access to all network users
- Thus, transparent & equitable rules must be used for
  - authorization of connection to the grid
  - allocation of limited transmission capabilities

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How to assign priorities for access?

- There is a diversity of situations
  - Requests to connect to the network
  - Solve local network constraints
  - Solve generalized network constraints

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Requests of connection to the grid

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Principles of access *(1 of 4)*
Requests of connection to grid

- Access for generators or consumers may only be restricted because of lack of network capacity
  - reinforce network if justified whenever possible
  - offer alternative connection points if proposed ones are not feasible
- Consumers have the right to be supplied at the requested point, but cannot displace prior consumers
- Different criteria may be applied to generators
  - a) same as for consumers
  - b) right to be connected at any point, even if in conflict with existing generators for the use of limited network capacity

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Principles of access *(2 of 4)*
Requests of connection to grid

- The objectives of connection charges is the recovery of costs of connection infrastructure *(& perhaps reinforcements)*
  - to an appropriate extent, considering benefits to other grid users
  - in this way providing (some) locational signals
- Connection costs depend on
  - distance from the existing network
  - capacity of the required connection
  - configuration of the (local) network

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Principles of access *(3 of 4)*
Requests of connection to grid

- Alternative charging approaches for connection assume different degrees of contribution to the cost of dedicated facilities and of network reinforcement *(& therefore of socialisation of these costs)*
  - **No charges** → all connection costs are socialised
  - **Shallow** charges → connection charges cover the cost of dedicated facilities (and possibly the cost of reinforcements in the local area); costs of (other) reinforcements are socialised
  - **Deep** charges → connection charges cover the cost of dedicated facilities and of all network reinforcements

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Principles of access *(4 of 4)*
Requests of connection to grid

- Reinforcements related to a new connection may benefit existing grid users as well
- Dedicated facilities for a new connection may benefit future connections
  - these facilities may become common to several grid users
  - the SO may decide to oversize these facilities
- No simple rule for definition of connection charges
  - Connection of small grid users may be generally charged on a shallow basis *(according to standardised values/criteria)*
  - Cost-related connection charges for large grid users and for non-standard connections *(e.g. very distant locations from the existing network)*

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Solution of **local** network constraints

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How to assign access priorities?
Local network constraints

- Market mechanisms versus regulated methods
  - MARKET
    - If the conditions exist for competition: the market rules must avoid introducing excessive risks for generators & consumers
      - Separated bids for the daily market & to solve network constraints
  - REGULATED
    - More appropriate for those situations where the market does **not** seem to be possible
    - This requires to transfer the knowledge on costs (at least in general terms) to the regulator & to reach a reasonable agreement

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Management of **generalized** network constraints

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How to assign access priorities? *(1 of 4)*

Generalized **network constraints**

Principles for allocation of limited network capacity

- Use, whenever possible, market mechanisms that do not discriminate any network users
- Do not allow long-term capacity reservations to result in market dominance
  - allocate firm capacity with market mechanisms
  - set upper limits to the fraction of capacity that can be auctioned
  - do not allow any single agent to control a large fraction of the auctioned capacity
  - unused capacity must be available for any buyer
  - possible ad hoc treatment of existing long term contracts

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How to assign access priorities? *(2 of 4)*

Generalized **network constraints**

- A diversity of solution schemes in the **short-term**, very dependent on the specific context
  - Nodal prices *(pioneer use in several countries in South America, in the Central American Market, widely used in US ISOs)*
  - Zonal prices or market splitting or implicit auctions *(Scandinavia, Italy, ERCOT initially; extensions of this scheme could be used to cover more than one centrally dispatched system)*
  - Redispatch &/or counter-trading *(these are solutions more internal to a market, or in simple configurations with two markets; less market-oriented)*

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How to assign access priorities? *(3 of 4)*

Generalized **network constraints**

- There is also the possibility to use different types of **long-term** contracts
  - Explicit auctions
    - Financial vs. physical rights
    - Point-to-point rights versus flowgates
  - Associated issues
    - Pre-existent contracts: compatibility with the market
    - Market power: limitations in the allocation rules
    - Rights that are linked to new generation investments

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How to assign access priorities? *(4 of 4)*

Generalized **network constraints**

- More sophisticated schemes are needed in **regional** markets
  - Centralized vs. Loosely coordinated vs. Basically independent
    - The Central American Electricity Market *(nodal pricing, N+1 markets, centralized dispatch of international trade)*
    - The EU Internal Electricity Market *(lack of global coordination; several tight sub-regional markets; attemps to tighter coordination, e.g. flow-based market coupling)*
    - The US ISOs / RTOs *(still very rudimentary coordination among them)*

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Details on methods for network constraint management

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The basic considered approaches

- Full **nodal** pricing
- **Zonal** pricing
  - network congestion results in economic islands, with different market prices
- **Redispatch** & **countertrade**
  - System Operator decides the optimal redispatch / counter flow that eliminates the congestion
- **Auctions** of network capacity
  - The congested capacity is offered for auction & only the winners can execute their transactions (explicit & implicit implementations are possible)

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Nodal *versus* zonal prices

- Network congestions result in economic islands with different market prices ➔ if distinct zones can be defined & prices are averaged within each one ➔ zonal prices
- These prices cause changes in generation & demand ➔ any network constraint violations are removed
- The congested line generates some income:

(transported energy) x (difference in prices between the two ends of the line)

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Redispatch / counter-trade

- **Redispatch:** The System Operator, using economic & technical information from the power system, decides the optimal dispatch that solves the congestion *(i.e. eliminates any constraint violation)*
  - The extra cost of the redispatch should be assigned to those agents that have the responsibility for it
- **Counter-trade:** (similar to redispatch) The SO decides to apply a physical transaction in the opposity direction so that the constraint violation is eliminated

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Network capacity contracts *(1 of 4)*

- These are risk hedging contracts that try to reduce or to eliminate economic risks that network congestions may cause in bilateral transactions
  - Loss of income if a generator is removed from dispatch because of network congestions
  - Price volatility that is caused by network congestions
  - Physical impossibility to perform the transaction
- Variants: physical vs. financial / line-based *(flowgates)* or node to node *(or zone to zone)*

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Network capacity contracts *(2 of 4)* Explicit capacity auctions

- Nodal or zonal prices are not required; compatible with any organization of the wholesale market
- Prior to the energy market, the limited capacity is auctioned to the agents affected by the congestion
  - Network capacity & energy market are artificially separated
  - (Conceptually) an implicit auction (resulting in nodal or zonal prices) would be superior
- Only the winning transactions *(in the auction)* may physically take place
- The auction generates some income

  (transported energy) x (auction price for that transaction)

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Network capacity contracts *(3 of 4)*

- Remember that the market value *(based on differences of nodal prices)* of a network capacity contract once built *(over the economic life of the asset)* is in general much less than the total cost of the corresponding transmission capacity
- Network transmission contracts have to adapt to any mecanism of congestion management that has veen adopted
  - if zonal prices are used ➔ FTRs must cover the price differential between the entry & exit nodes
  - if auctions are used ➔ FTRs are a particular form of explicit auctions

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Network capacity contracts *(4 of 4)*
Firm transmission rights (FTRs)

- FTRs are "contracts for differences" of the type

  Quantity Q x (nodal price k – nodal price j)
- Well designed FTRs have very useful properties
  - Simultaneous feasibility ➔ Revenue adequacy
- FTRs may increase market power problems
- It is important to understand the differences & coincidences of FTRs & physical transmission contracts
  - In the spot market
  - In emergency situations

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