Basics of Power Systems Planning and Operations

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The World Bank
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• Overview: power system functions

• From planning to operations: delivering electricity at all times

• Basics of planning

• Basics of operations

• Renewables and planning and operations
The physical structure

Profile of an Electric Power System

- Control center
- Generating plant
- Transmission substation
- Distribution substation
- Public networks
- Private microwave network
- Residential loads 35%
- Commercial loads 31%
- Industrial loads 34%

Source: PJM
Evolution of the different structures

1980’s

Vertically integrated utility

Regulated tariff

Consumer

Transmission

Operation

Distribution

Generation

90’s – 00’s

IPPS

Long-term contract

Reg. tariff

Consumer

Single buyer model

Wholesale competition

Spot market

Long-term contracts

Regulated tariff

Large consumer

Reg. consumer
Regardless of the structure the main goal of the system is to ensure that demand is met **adequately and securely**

- **Adequate**: The system is able to meet all demand needs today and in the future

- **Secure**: The system is able to meet demand despite unanticipated events such as failures (in supply or any components in the grid)

A system is **reliable** if it is **adequate** and **secure**
Once reliability is achieved quality is the next step

**Quality of service:** low number, duration, and severity of supply interruptions to particular sets of costumers

**Quality of energy:** the technical characteristics of the current and voltage wave-forms: harmonic contents, flickering, sagging

**Quality of attention:** how quick the utility (usually distribution or transmission company) responds to costumer’s requests: billing problems, connections, disconnections, questions, etc,
All the functions should be integrated so that the system works to deliver electricity at all times: adequately, securely, with quality and desired cost and environmental characteristics.

Transmission and distribution
- Expansion
- Access
- Tariff regulation
- Service quality

Generation markets
- Type and number of sport markets (day ahead, intraday)
- Bilateral contracts (physical, financial)
- Supply adequacy function: long-term signals for investment (capacity payments, reliability auctions)
- Demand Side Management (DSM) and Participation

Ancillary services
- Real time operations
- Reserves real and reactive
- Frequency control
- Voltage control
Adequacy, security, and quality are achieved in different ways by different market structures.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Adequacy Planning</th>
<th>Security Operations</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less competition</td>
<td>Planning</td>
<td>Operator manages all aspects in a central fashion</td>
<td>Almost to the will of the utility or to the strength if regulator</td>
</tr>
<tr>
<td></td>
<td>long-term</td>
<td>mid-term</td>
<td></td>
</tr>
<tr>
<td>More competition</td>
<td>Incentives and regulation: capacity payment, long term contracts, reliability auctions</td>
<td>System operator + competition in some of the ancillary services</td>
<td>By regulation of transmission and distribution business</td>
</tr>
<tr>
<td></td>
<td>mid-term</td>
<td>short-term</td>
<td>real-time</td>
</tr>
</tbody>
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• Overview: power system functions

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The name of the functions: \textit{vertically integrated structures (pure single buyer model)}

- \textbf{Planning}:
  - \textit{long-term} and \textit{mid-term}

- \textbf{Operations}:
  - \textit{mid-term}
  - \textit{short-term}
  - \textit{real-time}

\begin{itemize}
  \item \textbf{Long-term planning}
    \begin{itemize}
      \item Generation, transmission interconnections, demand side measures
    \end{itemize}
  \item \textbf{Hydro-thermal coordination}
    \begin{itemize}
      \item Unit-commitment
      \item Demand forecast, fuel needs, maintenance scheduling (G+T)
    \end{itemize}
  \item \textbf{Operations planning or economic dispatch}
    \begin{itemize}
      \item Demand forecast, transmission-limited unit commitment, optimal power flows, sc-ED or OPF
    \end{itemize}
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    \begin{itemize}
      \item Voltage control
      \item Protections
    \end{itemize}
  \item \textbf{Real time dispatch}
    \begin{itemize}
      \item Set-points to generators and AGC, Interchange scheduling
    \end{itemize}
\end{itemize}
The name of the functions: systems with considerable competition in generation

Planning
- long-term
- mid-term

Operations
- mid-term
- short-term
- real-time

Indicative integrated planning
Transmission planning
Capacity value determination
Reliability auction
Installed capacity markets
Bilateral contracts

Real-time markets
Balancing mechanisms
Ancillary services
“dispatch”: frequency control, voltage control, protections

Long-term water values
Unit-commitment

Day-ahead markets
Intra-day markets
Ancillary services procurement: reserves

Indicative names of some of the functions
Short-term dispatch function needs to be thoroughly organized from the technical and commercial perspectives.
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UNDERSTANDING PLANNING: SIMPLIFIED SCREENING CURVE ANALYSIS

- To define investment additions in generation that will supply demand adequately and securely, at minimum cost plus any other policy objectives of importance to the system (e.g. emissions, price volatility)

- Demand changes constantly and such variations need be taken into consideration when planning
• Long term generation planning

Long run planning to answer: What, when, and how to add new generation capacity to meet future demand?
UNDERSTANDING PLANNING: CONCEPTS

• Long term generation planning:
  • **What**: generation type (coal, nuclear, wind)
  • **When**: 2015, 2017?
  • **How**: how to combine sizes of coal, nuclear, wind, and other resources to meet changing demand patterns

• Plan should following desired objectives:
  • Minimum cost,
  • Balance emissions,
  • Increase use of local energy sources...
Conventionally, planning objective is to ensure demand will be met at minimum cost (other objectives or constrains can also be included)

- Capital cost of the different generation options
- Operational cost
  - Fixed operation costs
    Regular facilities work/maintenance) that do not depend on the power plant output
  - Variable operation cost
    e.g. Own-consumption, cooling etc, that depends on output MWh
- Fuel cost, which is also variable on output MWh
Capacity factor (CF): Measure of the actual energy production compared to the unit’s maximum production capacity.

- 0 < Low Capacity Factor < 0.3
- 0.3 < Average Capacity Factor < 0.5
- 0.5 < High Capacity Factor < 0.99

It all depends on how demand interacts with all generation units, dispatch/contract rules, and availability of units and their fuels.
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The name of the functions: **vertically integrated structures** (pure single buyer model)

- **Planning**
  - long-term
  - mid-term

- **Operations**
  - mid-term
  - short-term
  - real-time

(>1 year)

**Long-term planning**
Generation, transmission interconnections, demand side measures

(1 ~ 3 years)

**Hydro-thermal coordination**
Unit-commitment
Demand forecast, fuel needs, maintenance scheduling (G+T)

(1 day head)

**Operations planning or economic dispatch**
Demand forecast, transmission-limited unit commitment, optimal power flows, sc-ED or OPF

**Frequency control**
Voltage control
Protections
Real time dispatch
Set-points to generators and AGC, Interchange scheduling

**Indicative names**
Activities performed
The name of the functions: **vertically integrated structures** (pure single buyer model)

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**Voltage control**
**Protections**
Real time dispatch
Set-points to generators and AGC, Interchange scheduling

Indicative names
Activities performed
Short-term economic dispatch

• One of the most important functions before real-time operation

• Scope of the function
  • Usually performed **one day** before operations, up until a 30 or 15 minutes before real-time
  • The operator (system/market) knows what units are available to the system
  • The operator has an updated (more accurate) projection of system demand
  • The operator knows what are the conditions of the transmission system, and has good knowledge of possible contingencies

• **Objective:** to schedule existing generation to economically supply short-term demand
Basics: short-term generation economic dispatch

<table>
<thead>
<tr>
<th>Size (MW)</th>
<th>Fuel Type</th>
<th>Fuel Cost $/MMBTU</th>
<th>Fuel Consum MMBTU/MW-hr</th>
<th>Total Cost $/MW-hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Coal</td>
<td>5</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>200</td>
<td>Hydro</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>150</td>
<td>Gas</td>
<td>15</td>
<td>10</td>
<td>150</td>
</tr>
</tbody>
</table>

- Assumptions: There are no transmission limits and no losses
- Problem: at 8:00 it has been forecasted that demand at 9:00 will be 250 MW, how to supply this demand?
Basics: short-term generation economic dispatch...

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<th>Fuel Type</th>
<th>Fuel Cost $/MMBTU</th>
<th>Fuel Consum MMBTU/MW-hr</th>
<th>Total Cost $/MW-hr</th>
<th>Output MW</th>
<th>Cost $</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Coal</td>
<td>5</td>
<td>15</td>
<td>75</td>
<td>50</td>
<td>$3,750</td>
</tr>
<tr>
<td>200</td>
<td>Hydro</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>200</td>
<td>$1,000</td>
</tr>
<tr>
<td>150</td>
<td>Gas</td>
<td>15</td>
<td>10</td>
<td>150</td>
<td>0</td>
<td>$0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250</td>
<td>$4,750</td>
</tr>
</tbody>
</table>

- The minimum cost to supply 250 MW during one hour is $4,750.
- Lowest cost generator is dispatched first and highest cost generator dispatches last. There is “merit order”
Economic interpretation

• Generators produce output if price is above cost
• Demand is inelastic
• Intersection of supply and demand = price
It is 8:00 am, the dispatch for 9am has been made, now what?

- The production output for each generator is transmitted to the each generator Automatic Generation Control (AGC) “set-points”
It’s 9:00am, if everything is as forecasted this is the final dispatch=as planned previous day/hour=set points

<table>
<thead>
<tr>
<th>$/MW</th>
<th>Hydro</th>
<th>Coal</th>
<th>Gas</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>5</td>
<td>75</td>
<td>200</td>
<td>450</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
What if at 9:00am Hydro run outs of water and produces only 100 MW?

It could have been wind as well.
What if at 9:00am Hydro run outs of water and produces only 100 MW?

Gas power plant responds and quickly produces 50 MW, short-term generation cost (price) grows up to 150 $/MW
Short-term (operative) reserves are required to anticipate this situation:
In general short-term operation will look like:

<table>
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<tr>
<th>Time</th>
<th>Cost $/MW</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>5 $/MW</td>
</tr>
<tr>
<td>7.5</td>
<td>75 $/MW</td>
</tr>
<tr>
<td>15</td>
<td>150 $/MW</td>
</tr>
<tr>
<td></td>
<td>200$/MW</td>
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Simplified representation

Operative reserves

Total Gen Available

Demand MW

Time
The name of the functions: **vertically integrated structures** (pure single buyer model)

20 yrs

long-term  mid-term

Planning

2 yr

mid-term

Operations

2 days

short-term

30 min

real-time

3 secs

(>1 year)

**Long-term planning**

Generation, transmission interconnections, demand side measures

(1 ~ 3 years)

**Hydro-thermal coordination**

Unit-commitment

Demand forecast, fuel needs, maintenance scheduling (G+T)

(1 day head)

**Operations planning or economic dispatch**

Demand forecast, transmission-limited unit commitment, optimal power flows, sc-ED or OPF

**Activities performed**

- Frequency control
- Voltage control
- Protections
- Real time dispatch
- Set-points to generators and AGC, Interchange scheduling

**Indicative names**

Activities performed
It is 8:00 am, the dispatch for 9am has been made, now what?

- The production output for each generator is transmitted to the each generator Automatic Generation Control (AGC) “set-points”
What happens when demand increases (beyond dispatch level)?
System frequency is the signal that second by second tells if demand and generation are being matched.

Different generation technologies/controls provide frequency control in the millisecond, seconds, and minute time frame. Such services can all be called “operating reserves.”
Operating reserves: power output increase or decrease that can be achieved within prescribed time frames.

There is no standard to name reserves, each system may need different types of reserves. The following are typical types of reserves in a system:

- **Regulating Reserve**: Automatic, Within optimal dispatch, to correct the current ACE
- **Following Reserve**: Manual, Part of optimal dispatch, to correct the anticipated ACE
- **Contingency Reserve**: Instantaneous, to stabilize frequency, or return frequency to nominal and/or ACE to zero, for primary, secondary, and tertiary levels
- **Ramping Reserve**: Non-instantaneous, to replace primary and/or secondary, for secondary and tertiary levels

*Source: Operating Reserves and Variable Generation. A comprehensive review of current strategies, studies, and fundamental research on the impact that increased penetration of variable renewable generation has on power system operating reserves. Erik Ela, Michael Milligan, and Brendan Kirby. NREL aug. 2011*
Voltage. Same as frequency, voltage needs to be within prescribed limits to ensure both quality and reliability.

Devices that consumer reactive power: motors in pumps, fridges, anything that has a coils on it. Devices that produce reactive power: generator, capacitors, var compensators, lines.
In real time operations Frequency and Voltage are the main variables to control to ensure system security.

Virtually any device in the system has an impact on F and V.

Generation assess are specially important to manage F, and also (but to a lesser degree) V.

Frequency is a system issue, while voltage is a local issue (in a given region, substation, street area).

Operators have rules to use the different devices so that F and V are always within prescribed limits.
- New generation technologies such as Wind and Solar power have characteristics that make them different to other technologies

- These sources have variability in their power output somewhat different to the variability our systems are used to

- Their location is more sparse and their average size is somehow “smaller” than conventional power plants

- Almost all variables in the system (generation/demand) are variable in the short- and long-term.

- New RE, such as wind and solar have a different form of variability – one to which grid operators were not used to – in that such sources are more uncertain and offers less (or non) controllability.
IMPACTS IN DIFFERENT TIME/SPACE FRAMES AND THE ARE OF FOCUS IN THIS PRESENTATION

- Short Circuit
- Power Quality
- Sub-synchronous resonance
- Angle Stability
- DynamicFreq. Response
- AGC and Primary Response
- Secondary Reserve
- Tertiary Reserve
- Real Time Dispatch
- Primary Response
- Tertiary Reserve
- Short-term and mid-term dispatch
- Transmission constraints
- Transmission & adequacy
- Supply adequacy

Time frames:
- 0 ms
- 10’s ms
- 10’s sec
- 10’s min
- 10’s hrs
- 10’s years

System wide
Regional
Local
In the planning perspective, adequacy T&D

- Enough generation to comply with planning criteria (renewables contribute differently to supply adequacy)
- Transmission to connect renewables
- Planning to consider the differences of var RE
In the operational perspective

- Ensure renewables are dispatched reliably and efficiently

- Enough operational reserves to cope with system in general but also given additional variability

- Dispatch rules to incorporate forecasting and new reserves needs
**In the electrical perspective**

- Ensure system continues to maintain V & F
- Renewables contribute positively to maintain F and V or at least do not deteriorate them
- Grid codes to specify the requirements