Reactive Power

Is it real? Is it in the ether?

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Views expressed are not necessarily those of the Commission.
alternating current (AC) systems

- produce and consume two kinds of power:
  - real power (measured in volt-amperes or watts) and
  - reactive power (measured in volt-amperes reactive or vars).

- Real power accomplishes useful work (e.g., running motors and lighting lamps).

- Reactive power supports the voltages that must be controlled for system reliability.

- Reactive power may be supplied by
  - switched shunt capacitors,
  - static var compensators, STATCOM
  - generators and synchronous condensers.

- Reactive power does not travel over long distances at high line loadings due to significant losses on the wires.
Physical characteristics and costs

- Reactive power support can be divided into:
  - Static
  - Dynamic.

- Static reactive power e.g. from capacitors
  - Drops when the voltage level drops.
  - Low costs

- Dynamic reactive power e.g. from generators
  - Does not fall when voltage drops
  - Higher costs.
# Characteristics of Voltage-Control Equipment

<table>
<thead>
<tr>
<th>Equipment type</th>
<th>Speed of response</th>
<th>Voltage Support</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>Fast</td>
<td>Excellent short-term capacity</td>
<td>Low</td>
</tr>
<tr>
<td>Synchronous Condenser</td>
<td>Fast</td>
<td>Excellent short-term capacity</td>
<td>Low</td>
</tr>
<tr>
<td>Capacitor</td>
<td>Slow</td>
<td>Poor, drops with $V^2$</td>
<td>High</td>
</tr>
<tr>
<td>Static VAr Compensator</td>
<td>Fast</td>
<td>Poor, drops with $V^2$</td>
<td>High</td>
</tr>
<tr>
<td>STATCOM</td>
<td>Fast</td>
<td>Fair, drops with $V$</td>
<td>High</td>
</tr>
<tr>
<td>Distributed Generation</td>
<td>Fast</td>
<td>Fair, drops with $V$</td>
<td>Low</td>
</tr>
</tbody>
</table>
A generator’s cost of producing reactive power depends on the thermal and stability limits of the generator.

When operating at certain limits, it can increase its production or consumption of reactive power only by reducing its production of real power.

As a result, producing additional reactive power results in reduced revenues associated with reduced real-power production.

Include opportunity costs associated with forgone real power production.
Generation Capability Curve

- Field Heating Limit
- 0.85 PF
- Armature Heating Limit
- Prime Mover Limit
- 0.95 PF
- Core End Heating Limit

REAL-POWER OUTPUT (MW)
Order No. 888 issued in April 1996.

Reactive supply from generation is an ancillary service.

Two ways of supplying reactive power:
- Transmission costs are basic transmission service.
- Generation unbundled from basic transmission service.

If market power, rates should be cost-based price caps.

Rates may be discounted.

Opinion 440: Generation plant related to reactive power:
- The generator and its exciter.
- Electric equipment that supports the generator-exciter.
- The remaining total production investment in the exciter.

Allocation factor: $\frac{\text{Mvar}^2}{\text{MVA}^2}$

Under the control of the system operator.

Comparability.
*Generation Interconnection Rule, Order 2003, for reactive power*

- A generator should not be compensated for operating within its established power factor range.
- The required range is 0.95 leading and 0.95 lagging.
- It may establish a different power factor range.
- It must compensate for reactive power during an emergency.
- If a transmission provider pays its own/affiliated generators for reactive power, it must also pay IPP.
ISOs and RTOs compensation to generators for reactive power

- Most pay generators their allocated revenue requirement or other capacity payment.
- Some pay its lost opportunity costs.
- Some impose penalties on generators for failing to provide reactive power.
International experience

- In England and Wales, a generator can accept a default payment of ~ $2.40/Mvarh leading or lagging, or it may offer contracts with a minimum term of one year.

- In Australian ISO, generators and synchronous condensers receive an availability payment, an enabling payment when dispatched and opportunity costs from forgone sales of real power.

- In India, the regulator imposes a 4 paise/kvarh (~$1/Mvarh) price on reactive power when the 1.03 < voltage < .97

- In the Netherlands, generators are contracted are paid for reactive power capability and no additional payment is made when it is supplied.

- In Sweden reactive power is supplied by generators on a mandatory basis, and there is no compensation.
Literature review

- Schewpe et. al. (1988) method for hourly real-time real electricity prices
- Baughman and Siddiqi (1991) simultaneous pricing of real and reactive power
- Hogan (1993)
  - DC load models are not sufficient
  - the price of reactive power is not negligible.
- Kahn and Baldick (1994): Hogan’s example is not realistic
  - Capacitors (plastic) are the answer
  - Reactive power is too cheap to meter
- PJM Reactive Services Working Group (2001) proposed
  - centralized planning with decentralized bidding for capacity projects
  - two-part tariffs to encourage capacity and performance

Issues
- Transactions costs: is it worth it?
- can optimal power flow models be modified
- efficient market with minimal intervention: market power
important goals and questions

- encourage efficient and cost-effective investment in infrastructure
- maintain the reliability of the system.
- encourage efficient dispatch and use of the existing infrastructure
- Can a market work? Yes with a good market design
- Do we need a cost-benefit study? Yes, of course
- Do market participants respond to price signals? Yes
whether or how such generators should be compensated for reactive power.

Hogan: its important

Kahn and Baldick: too cheap to meter

the need for differs by location.

Without payment for reactive power capability some older generators may retire

Comparable compensation for all generators

Compensation for static versus dynamic reactive power.
Should generators be compensated?

- One view is that generators should not be compensated for reactive power within specified limits as a condition of interconnection.
- They should bear the costs of maintaining this capability as well as the costs of producing reactive power from this minimum capability.
- Moreover, this requirement imposes little burden on generators because the costs of providing reactive power are typically small.
- The rationale offered by proponents is a version of 'good utility practice.'
ISO/RTO
pricing options

- capacity payment options
  - cost-based payment (Opinion 440)
  - Capacity market payment (ICAP)
  - Co-optimized auction (LICAP plus)
  - Pay nothing (good utility practice)

- spot pricing options
  - Pay nothing (good utility practice)
  - Unit-specific opportunity costs (D-curve)
  - Market clearing price auctions (marginal value)
  - Prices announced in advance (simple approach)
reactive power
market power

- markets may have market power
- cost-of-service mitigation can blunt and distort incentives
- AMP mitigation
- market power may be a smaller problem if entry and exist may become much easier.
- equipment that now comes in smaller mobile (e.g., truck mounted) increments
- Convert old generators
Spot markets for reactive power

- Integration of reactive power in spot markets has the potential to reduce the total costs of meeting load substantially.
- Software development is needed
- Simulation and experimentation are needed to understand the effects of alternative auction market designs before such a spot market is implemented.
## Co-optimized P/Q markets

### Node A
- Generator: 1000 MW, 500 Mvar
- Bid: $10/MW

### Node B
- Generator: 500 MW, 150 Mvar
- Bid: $80/MW

### Table:

<table>
<thead>
<tr>
<th>Bus</th>
<th>$V_B$</th>
<th>Cost</th>
<th>Gen A</th>
<th>Gen B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$P$</td>
<td>$PLMP$</td>
</tr>
<tr>
<td>Gen B &lt; 150 Mvar</td>
<td>.91</td>
<td>$20,647</td>
<td>905</td>
<td>$10</td>
</tr>
<tr>
<td>Gen B &lt; 400 Mvar</td>
<td>.94</td>
<td>$15,196</td>
<td>983</td>
<td>$10</td>
</tr>
</tbody>
</table>
Computational considerations

“perennial gale of creative destruction” Schumpeter

- 1996: LMP in New Zealand
  - 300 nodes; transmission constraints are manual
- 1990s: linear programs improved by $10^6$
  - $10^3$ in hardware; $10^3$ in software
- 2000s: mixed integer design improved by $10^2$
  - Hardware: parallel processors and 64 bit FP
  - Software: better performance
- New modeling capabilities in MIP
- 2006: 30000 nodes
  - $10^4$ transmission constraints; $10^3$ n-part generator bids
- 2010: co-optimized reactive and transmission
“Every great movement must experience three stages: ridicule, discussion, adoption” John Stuart Mill

Is ether returning as dark matter?