Reactive Power
Is it real? Is it in the ether?

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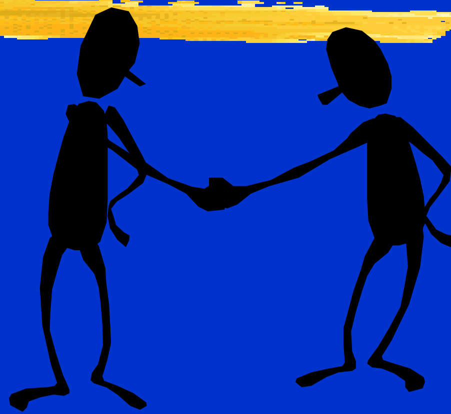

Harvard Electricity Policy Group
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Views expressed are not necessarily those of the Commission

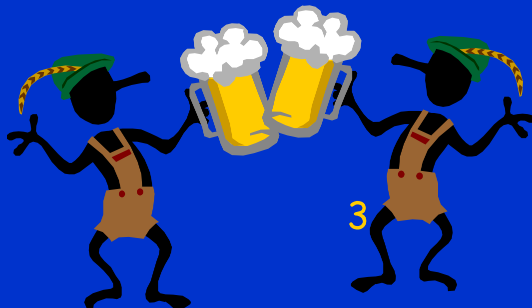
alternating current (AC) systems

- 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

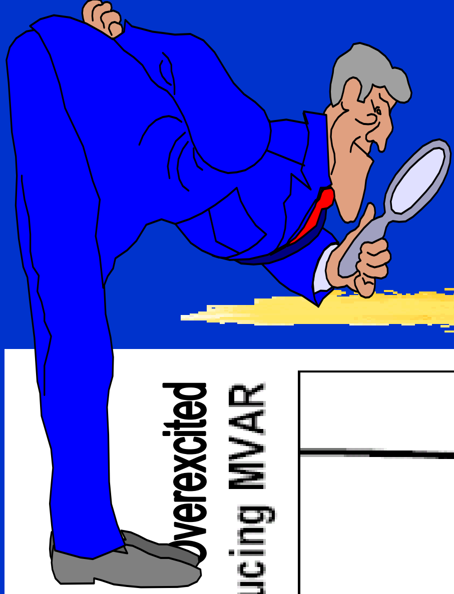
Equipment type	Speed of response	Voltage Support			Costs		
		Ability	Availability	Disruption	Capital (/kvar)	Operating	Opportunity
Generator	Fast	Excellent short-term capacity	Low	Low	Difficult to separate	High	Yes
Synchronous Condenser	Fast	Excellent short-term capacity	Low	Low	$30-35	High	No
Capacitor	Slow	Poor, drops with V^2	High	High	$8-10	Very low	No
Static VAr Compensator	Fast	Poor, drops with V^2	High	Low	$45-50	Moderate.	No
STATCOM	Fast	Fair, drops with V	High	Low	$50-55	Moderate	No
Distributed Generation	Fast	Fair, drops with V	Low	Low	Difficult to separate	High	Yes

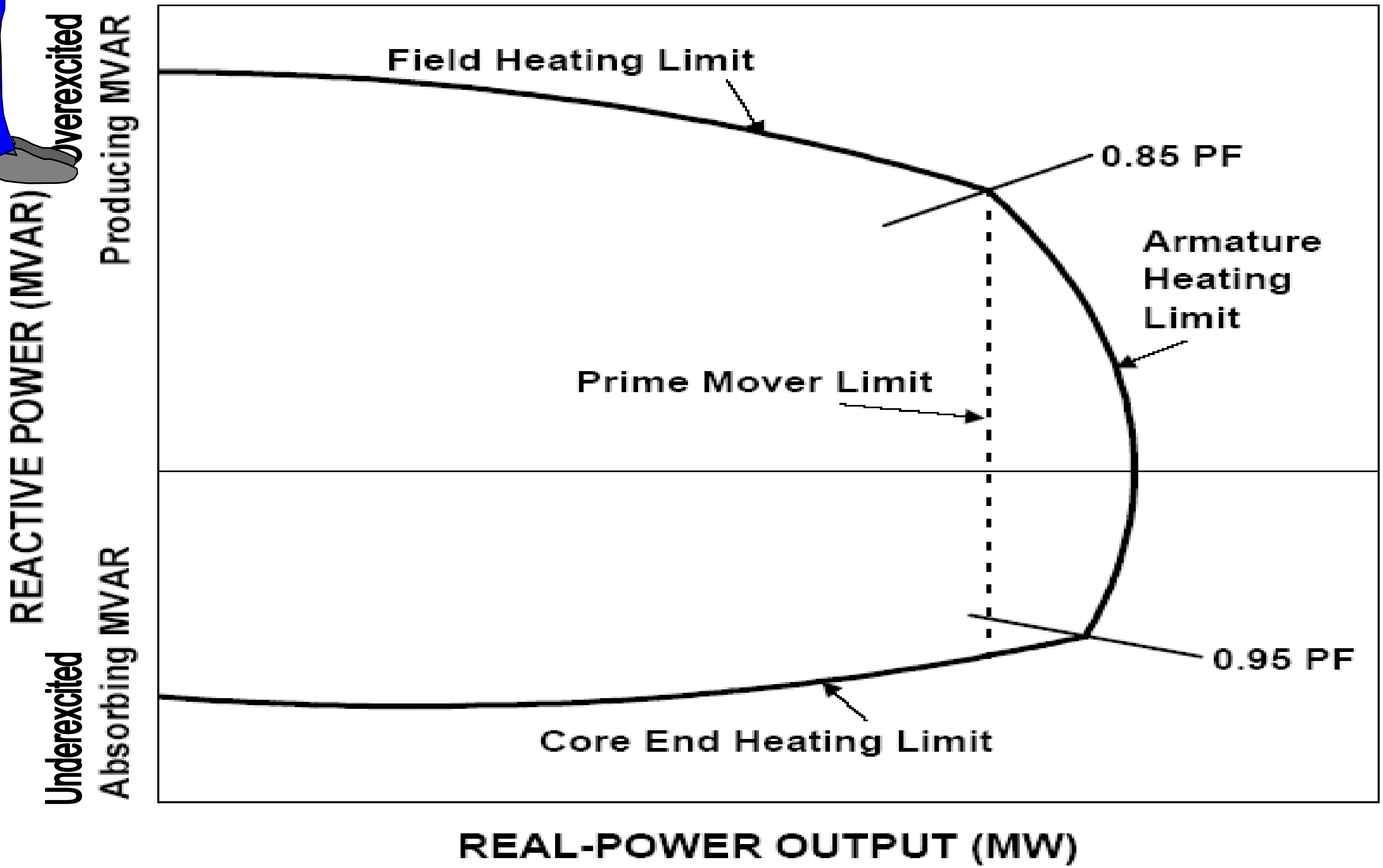
A generator's cost of producing reactive power

- 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

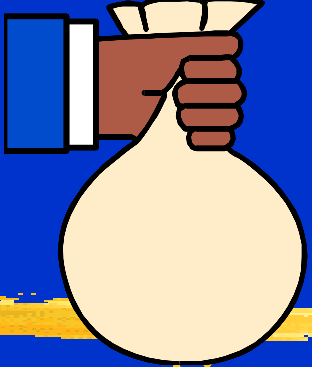




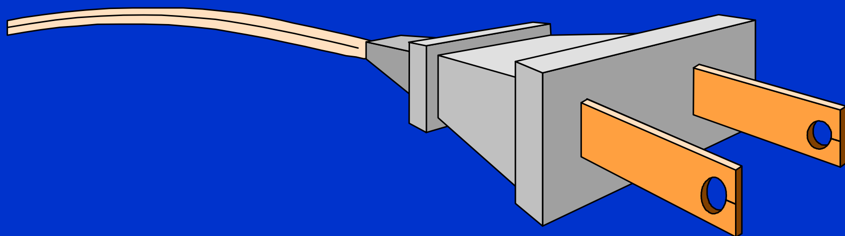
Order 888 reactive power pricing

- 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: Mvar^2 /MVA^2
- under the control of the system operator.
- comparability

Generation Interconnection Rule, Order 2003, for reactive power

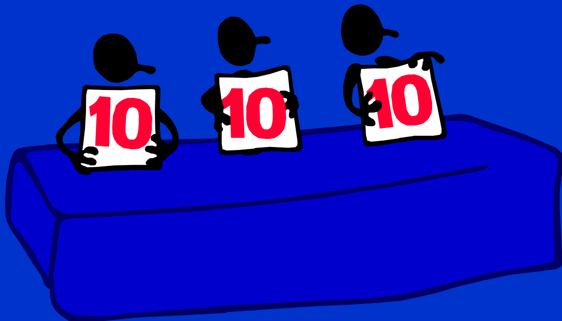


- generator should not be compensated for operating within its established power factor range.
- the required range is 0.95 leading and 0.95 lagging
- may establish a different power factor range.
- must compensate for reactive power during an emergency.
- if a transmission provider pays its own/affiliated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

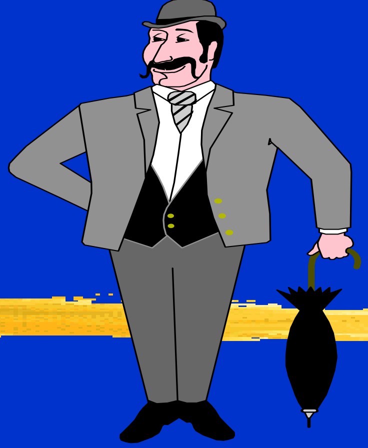


ISOs and RTOs compensation to generators for reactive power

- 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

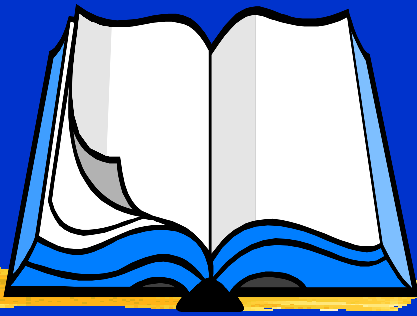


International experience



- 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
  - 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

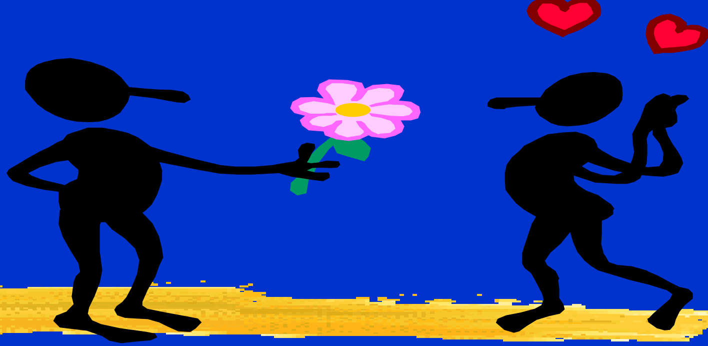


- Schweppe et. al. (1988) method for hourly real-time real electricity prices
- Baughman and Siddiqi (1991) simultaneous pricing of real and reactive power
- Hogan (1993)
  - DC load models are not sufficient
  - the price of reactive power is not negligible .
- Kahn and Baldick (1994): Hogan's example 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

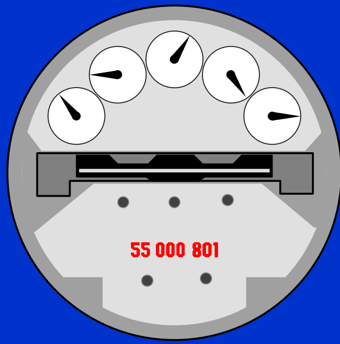
important goals and questions

- 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

reactive power market design issues



- whether or how such generators should be compensated for reactive power.
- Hogan: its important
- Kahn and Baldick: too cheap to meter



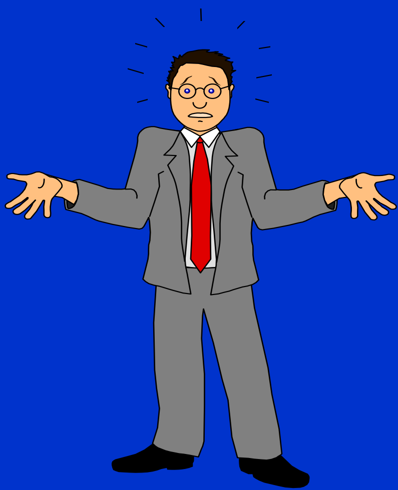
- the need for differs by location.
- Without payment for reactive power capability some older generators may retire
- Comparable compensation for all generators
- Compensation for static versus dynamic reactive power.

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'

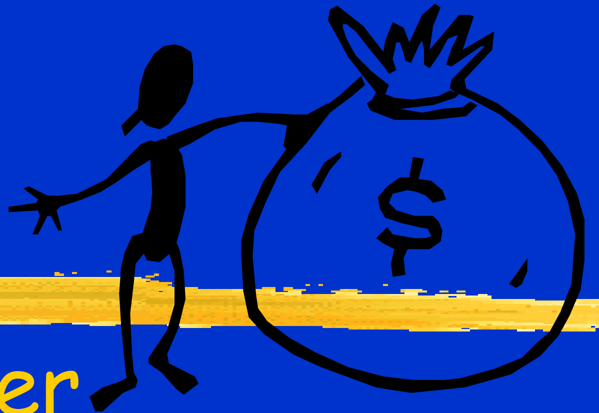
ISO/RTO pricing options

- 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

AB
bid =$0/MW
capacity: 600 MVA

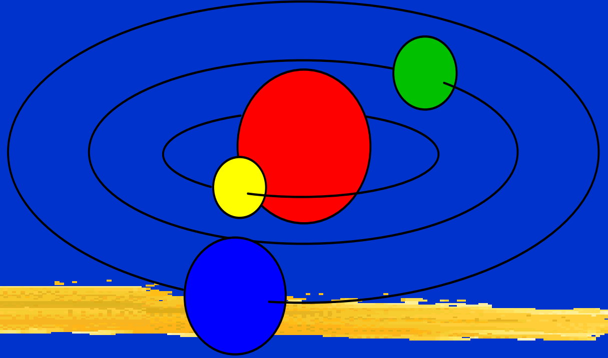
Node B
demand: 1000 MW
500 Mvar
Generator : 500 MW
150 Mvar
bid =$80/MW

bus	V_B	cost	Gen A				Gen B			
			P	PLMP	Q	QLMP	P	PLMP	Q	QLMP
Gen B < 150 Mvar	.91	$20,647	905	$10	424	$0	145	$80	150	$33
Gen B < 400 Mvar	.94	$15,196	983	$10	182	$0	67	$80	390	?

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?