OE Visualization and Controls Peer Review

Reliability as a Public Good

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Reliability as a Public Good

- A public good is a shared commodity like a street sign such that use by one does not reduce the enjoyment of another. But, unlike private goods, use is not exclusive which leads to free riding and under-provision.
- The Northeast power outage of August 2003 demonstrated that provision of public goods such as reliability, voltage, and frequency were not adequately considered in restructuring electric power.
- The conceptual framework used by FERC (as exemplified in the FERC report on reactive power) and others to justify markets is based on a set of economic/engineering models that fail to model the true economic optimum and identify the public goods necessary for optimal reliability.
- This work attempts to lay out an appropriate conceptual framework for analyzing power markets, provide simulations and experiments that show both an ideal system and the potential for market power in real time markets, draw research conclusions and make specific recommendations for market structure and operation that properly takes into account the need for reliability.

Markets should be structured to solve the true economic/engineering optimization problem

Efficient markets should maximize probability weighted net-benefits. In our analysis these consist of:

- Benefits to electricity customers
- Minus the costs of production of generators
- Minus any damages from deviations in voltage
- Minus local delivery and maintenance costs
- Minus the costs of building generators
- Minus the costs of installing reactive compensation
- Minus the costs of building lines

The AC network model and simulation used in the analysis of efficient power markets include:

- Real power
- Reactive power
- Voltage
- AC line flows
- Line failure
- Generator capability curves
- Generator failure

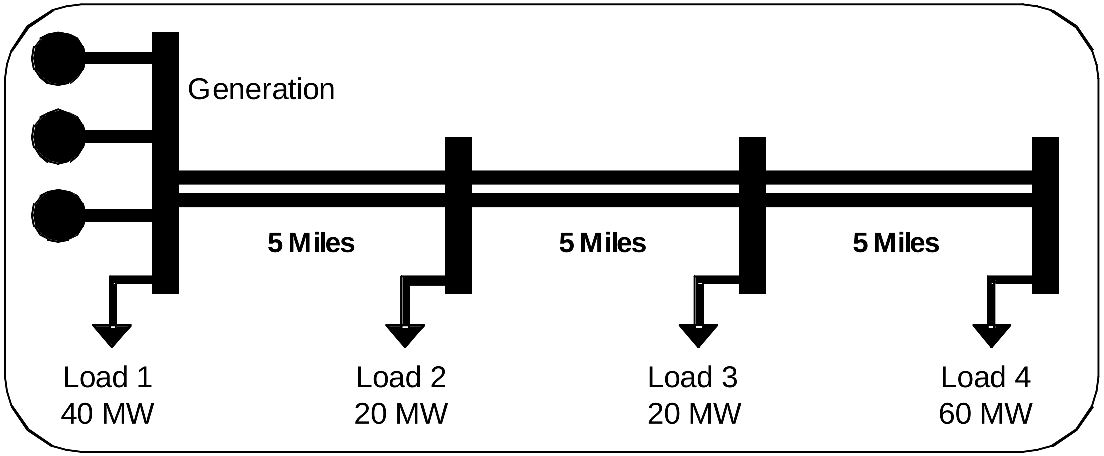
The model also includes:

- Demand for electricity from reliability studies
- Damages from voltage deviation
- Optimal investment in generators
- Optimal investment in lines
- Optimal installed reactive compensation

Public goods

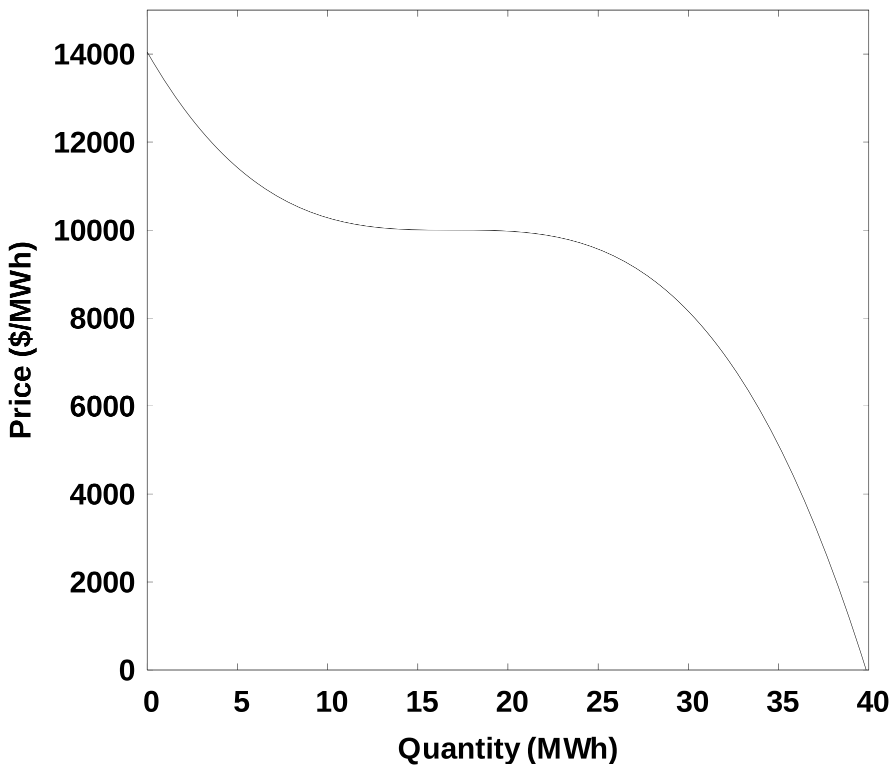
- The Reliability of Lines is a Public Good.
- Voltage is a Public Good
- Frequency is a Public Good
- Private markets under-supply public goods because users only consider the value to themselves, not to the system as a whole.
- Real and reactive power are private goods.
- Since reactive power is critical to maintaining voltage and reliability, the provision or reactive power through markets should be undertaken with great care even though it is a private good.

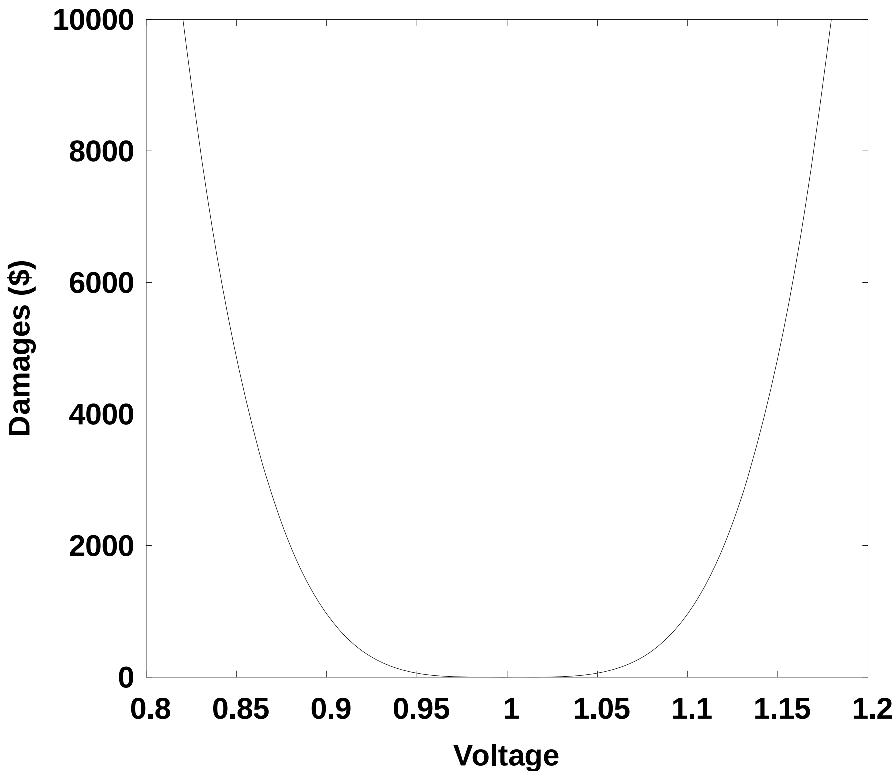
Simulating an example optimal network



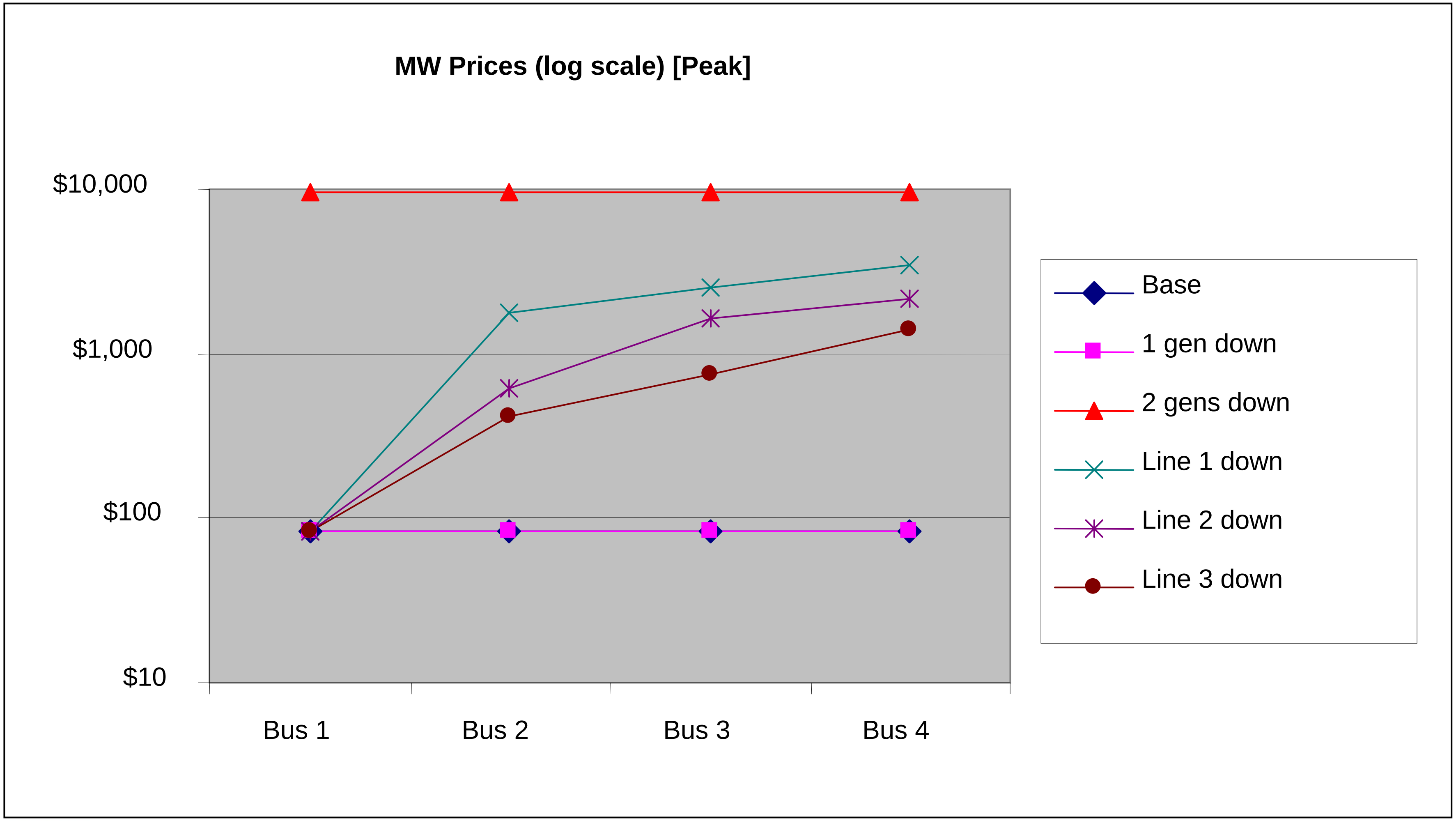
This network serves an “island” and has generation at one bus and several buyer busses extending out in sequence. The busses represent substations, and it is assumed that the distance between any two busses is five miles. The busses are connected by two parallel lines. Each of the six line segments can fail with a probability of 0.0005. Each of the three generators can also fail with a probability of 0.04. To keep the analysis manageable, the highly unlikely states of multiple failures at the same time are ignored.

Demand and voltage damages at peak load

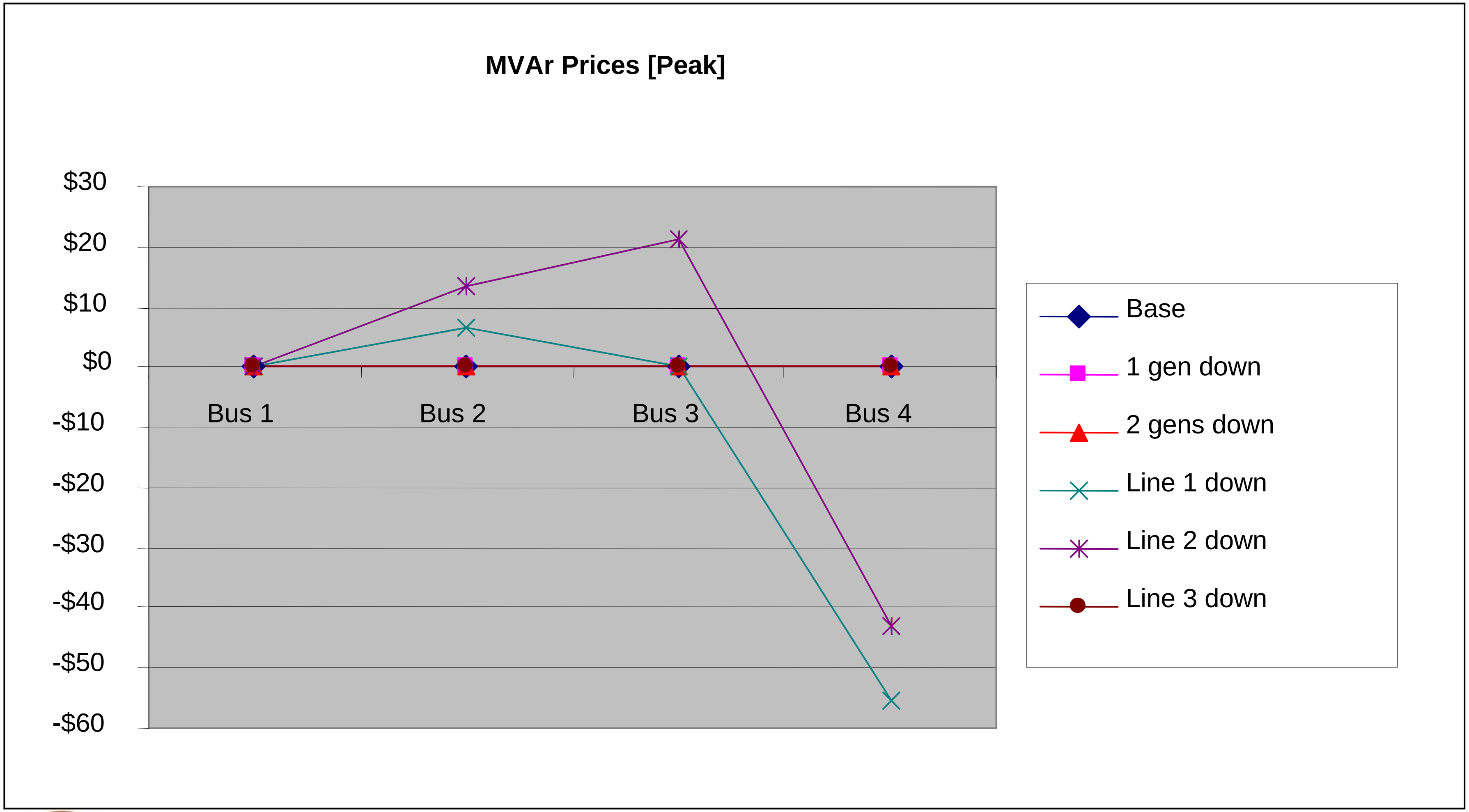




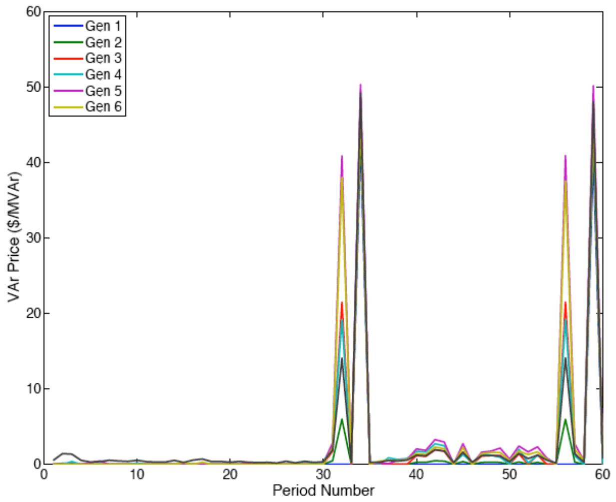
The base-state MW prices equal the marginal costs of production and basic delivery. When a generator fails, prices reflect the marginal value of the scarce real power. When a line fails, the prices are higher at all busses beyond the first, reflecting added transmission costs. Higher prices are required in both of these cases to get buyers to reduce their consumption.

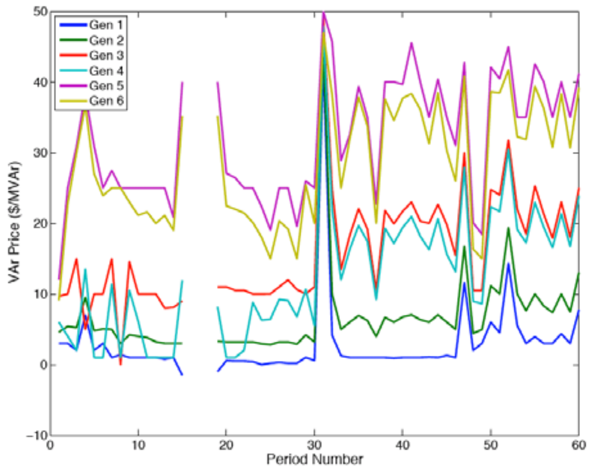


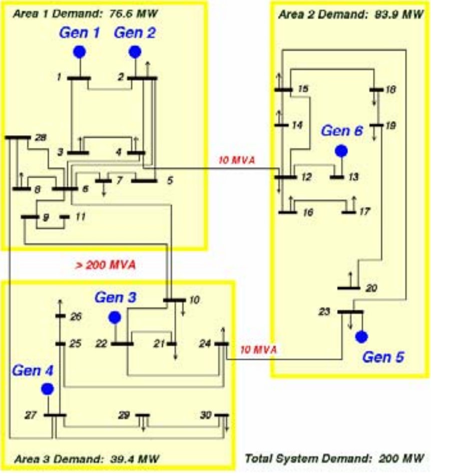
Most of the time, the price of reactive power is zero. However, enough revenue is generated to pay for the installation of both capacitors and inductors. This suggests then that competitive market-based installation could result in optimal quantities.



Market Power and VArs







- Extensive experiments have been run at Cornell using the 30 bus system shown here.
- The interplay between congestion, reactive dispatch, and voltage limits can easily lead to market power because of the inability to transmit VArs over long distances.
- An energy market alone with contracts with for VArs leads to the upper picture on the left.
- A market with offers for VArs from generators leads to the lower picture on the left and very high prices for VArs.
- Optimally VAr prices should be near zero most of the time!

CERTS
Consortium for Electric Reliability Technology Solutions

Research Conclusions

- **Although network reliability has long been identified as a public good, voltage, and frequency have not** because of the incomplete nature of existing DC models.
- Both **real power and reactive power are technically private goods** since they are excludable and rival.
- Simulation of optimal operation under different contingencies demonstrates that **nodal reactive power prices are almost always equal to zero if optimal investment in reactive power sources (e.g., generators and reactive power compensators) occurs throughout the system.**
- The average or expected **revenue derived from sale of reactive power at optimal real time prices during rare contingencies is sufficient to provide incentives for optimal private investment in reactive power capacity. However, this is a highly volatile and uncertain source of revenue** that depends on rare contingencies actually occurring.

Research Conclusions (cont.)

- However, both simulation and economics experimentation show that **opportunities for the exercise of market power by private suppliers of reactive power in real time markets are plentiful** in a network environment.
- Whereas virtually all demand for real power comes from private buyers, **demand for reactive power comes from private buyers and the from the central authority acting in the public interest as an input to the provision of a public good, voltage.**
- Optimal real power prices show greater upside volatility than optimal reactive power prices, principally because investment in generation is so expensive that it cannot optimally cover all contingencies. **Optimal generation investment does conform to the conventional wisdom of covering the worst single contingency by meeting load with the loss of the "largest" generator** in the simulation.
- Optimal investment in lines in the simulation is sufficient that **thermal line constraints are never binding**, even during contingencies.

Recommendations

- The first conclusion presented above, that some central authority is needed to provide the public goods of reliability and voltage (as well as frequency), implies that electric power does not lend itself to the degree of decentralized decision-making present in typical markets. **A Central Authority is needed because current independent system operators do not have authority for planning and design.**
- For the central authority to act in the public interest and be able to optimize the system, as well as provide necessary public goods, **a robust AC OPF program is needed that is able to do both the real and the reactive power problems properly.**
- Conclusion 3 states that reactive power prices will mostly be zero. When a real time market for a private commodity has financial transactions on rare occasions, since markets are expensive to operate, natural economic forces will restructure the market to avoid transactions costs. The commodity used in these markets is called a contingent claim, which is a claim for services that can be made only if one or more specified outcomes occur. **Thus, a contingent claim market is needed for reactive power.**
- Because the central authority responsible for reliability and operations needs reactive power on demand to deal with contingencies to assure reliability (conclusion 6), but substantial investment to meet that demand must be assured in advance (conclusion 4), **the reactive power market must be run well in advance of any contingency to assure needed supply.**

Recommendations (cont.)

- Market power is a serious problem for reactive power (conclusion 5). Since overall demand for reactive power comes in great part from the central authority responsible for system operations and reliability to meet public needs, **we recommend that contingent claim auctions for reactive power be run sufficiently far in advance to allow construction to occur (3-5 years)**, so that existing suppliers are placed in competition with potential new sources of reactive power,
- Capped real power prices paid to generators, as is common in US power markets, will provide insufficient incentives for investment in generation to assure optimal reliability. **Thus, we support measures to supplement generation investment if prices to generators are capped.**
- To provide incentives for conservation of real and reactive power demand, **large customers and marketers should pay real time nodal prices for real and reactive power** as derived from the system AC OPF.
- Proper incentives require that **transmission fees must be equal to the nodal price differences for real and reactive power derived from a full AC power flow** and applied to transmission of both real and reactive power. Note however, that transmission fees may be usually near zero with optimal line investment but tend to be positive during contingencies. As in the case of reactive power markets, real time markets may be inappropriate. To assure efficiency and reliability, **the central authority must plan and manage transmission.**

Publications

- David Toomey, William Schulze, Richard Schuler, Robert Thomas, James Thorp, "Reliability, Electric Power, and Public Versus Private Goods: A New Look at the Role of Markets," *hicss*, p. 58b, Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 2, 2005.
- Richard E. Schuler, "Market Design, Reliability and Infrastructure Investment," *hicss*, p. 57, Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 2, 2005.
- Nodir Adilov, Thomas Light, Richard Schuler, William Schulze, David Toomey, Ray Zimmerman, "Market Structure and the Predictability of Electricity System Line Flows: An Experimental Analysis," *hicss*, p. 59b, Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 2, 2005.
- Hyungna Oh, Tim Mount, "Testing the Effects of Holding Forward Contracts On the Behavior of Suppliers in an Electricity Auction," *hicss*, p. 61a, Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 2, 2005.
- Nodir Adilov, Richard E. Schuler, "Electricity Markets: How Many, Where and When?," *hicss*, p. 243b, Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06) Track 10, 2006.
- Jaeseok Choi, Timothy Mount, Robert Thomas, "Transmission System Expansion Plans in View Point of Deterministic, Probabilistic and Security Reliability Criteria," *hicss*, p. 247b, Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06) Track 10, 2006.
- Bernard C. Lesieutre, HyungSeon Oh, Robert J. Thomas, Vaibhav Donde, "Identification of Market Power in Large-Scale Electric Energy Markets," *hicss*, p. 240b, Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06) Track 10, 2006.
- In addition, the research team has recently prepared a White Paper on Reactive Power Markets.