

System Implications of Distributed Generation: Economics and Robustness

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Introduction to DG

Introduction to economic implications of DG systems

- DG provides energy and emissions savings (CO_2 , SO_2 [NO_x ?]) for a single installation provided consistent electricity and heat loads are available.
 - » High overall efficiency, use of natural gas, avoidance of electricity transmission
 - » Heat to power ratio (HPR) a key parameter
- BUT
 - » DG requires widespread use for significant economic & emission savings
 - » DG represents an alternate paradigm of energy generation and delivery
 - » DG introduction into existing energy system is a path dependent process

Outline ‘green-field’ energy system optimization model

Compare DG system architecture vs. conventional electricity & heat-only system architecture

Cost, gas use and emissions savings from DG system

Evolution of an energy system with existing plants and networks

Stranded assets

DG deployment issues

A 'green-field' cost optimization model of DG

Will DG's economic & emission savings translate to an energy system?

- MILP optimization for an integrated generation and delivery system for electric power and heat.
 - » Minimize total cost: sum of capital investment in plant and network, fuel costs, O&M costs
 - » Optimize over 15 years, with costs pro-rated at 10%
 - » Selection of distributed and centralized energy technologies, providing electricity-only, heat-only or cogeneration.
 - » Transmission infrastructure: electricity, gas, heat
 - » Decision variables
 - number of plants (integer), hours operated per technology and per demand period
 - » Constraints
 - Demand constraints each period for electricity and heat
 - Plant availability, heat load by population density, non-negativity

Available technologies

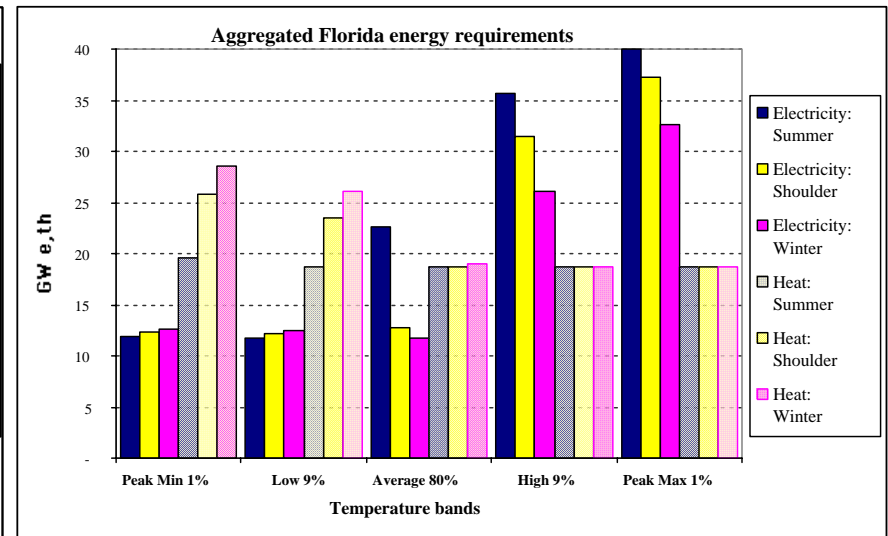
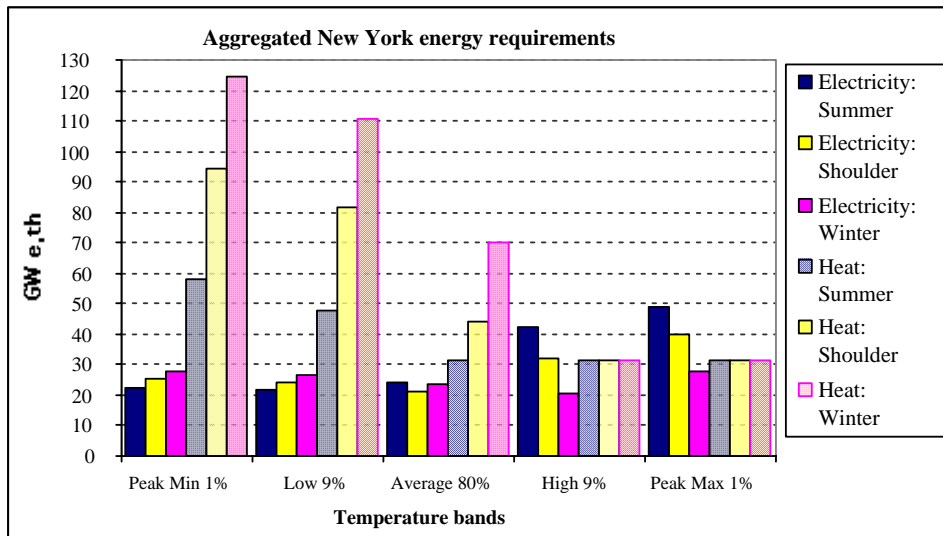
(based on natural gas - focusing on generation and network synergies)

	Centralized (>50MW)	Intermediate (1-50MW)	Distributed (100kW - 1MW)	Micro- distributed (5kW- 100kW)
Electricity only	CCGT <i>[Coal ST]</i>	Gas turbine (elec)		
Cogen	Steam turbine	Gas turbine	IC Engine	Micro- engine
Heat only			Heat boiler	

Derivation of variable energy demands

New York-heat led ; Florida-electricity led

- Analysis of seasonality of demand and varying heat to power ratios (HPR).
 - » Yearly season: summer, winter, shoulder
 - » Demand periods: determined by temperature bands, focusing on peak electricity and heat requirements
 - » Sectoral load aggregation: industrial, commercial, residential.



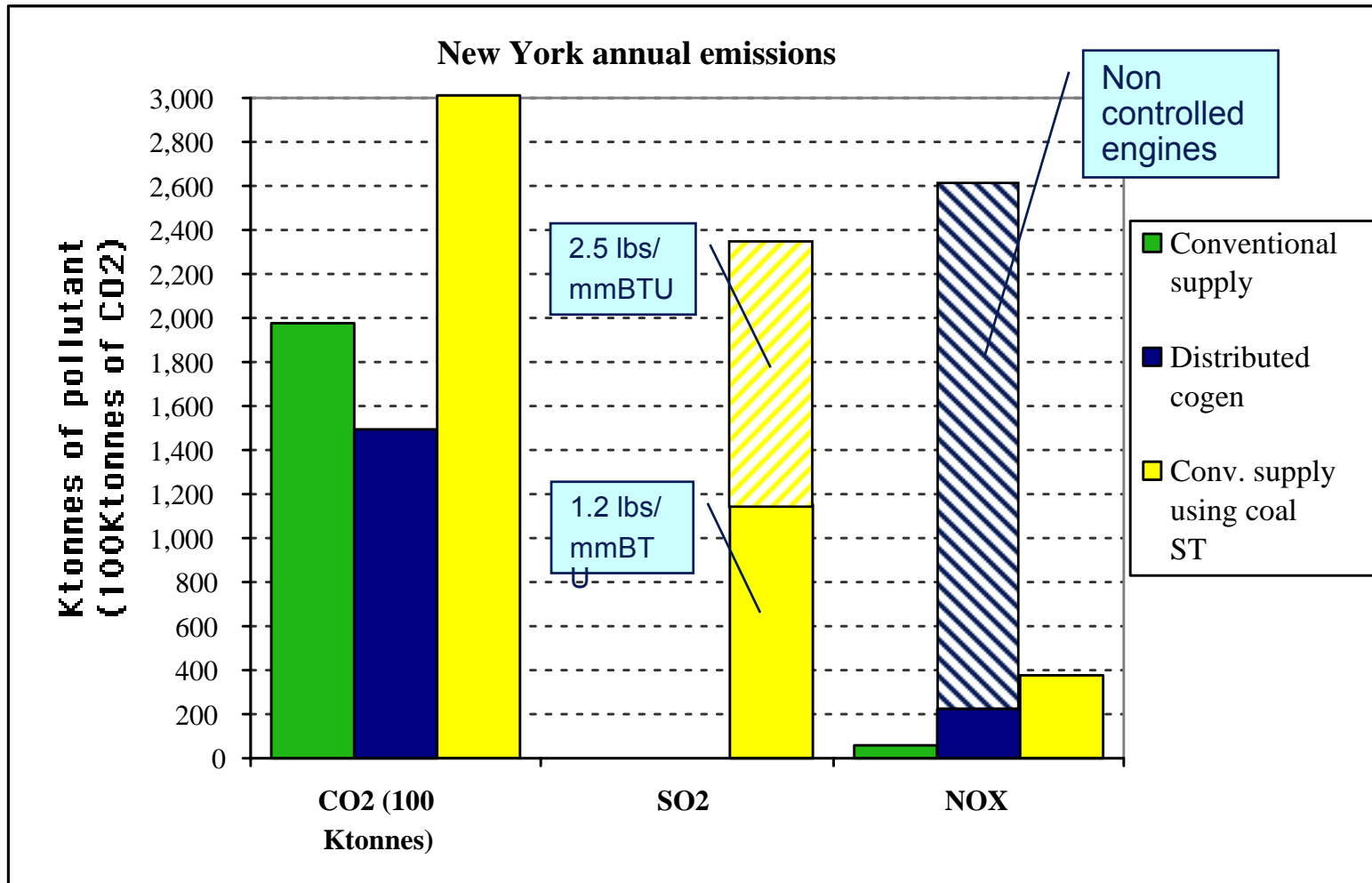
Cost savings from a DG based system architecture

- DG (run as cogen) is lowest cost technology: but requires consistent electricity and heat demands ratios (HPR)
- Energy system savings using DG are substantial
 - » New York realizes higher savings (30%) than Florida (21%), as large heat output from IC engines are better utilized
- Results robust following sensitivity analysis on capital costs, O&M costs, discount rate and natural gas prices
- DG reduces natural gas use vs. centralized gas-fired plant
New York - 26% savings ; Florida - 24% savings
 - » Seasonal gas use reductions depend on matching HPRs for max savings, and are improved through portfolio of plant types

DG reduces CO₂ even if all plants are natural gas fired

Comparing to coal fired ST increases CO₂ savings and gives SO₂ savings

NO_x picture is more complex

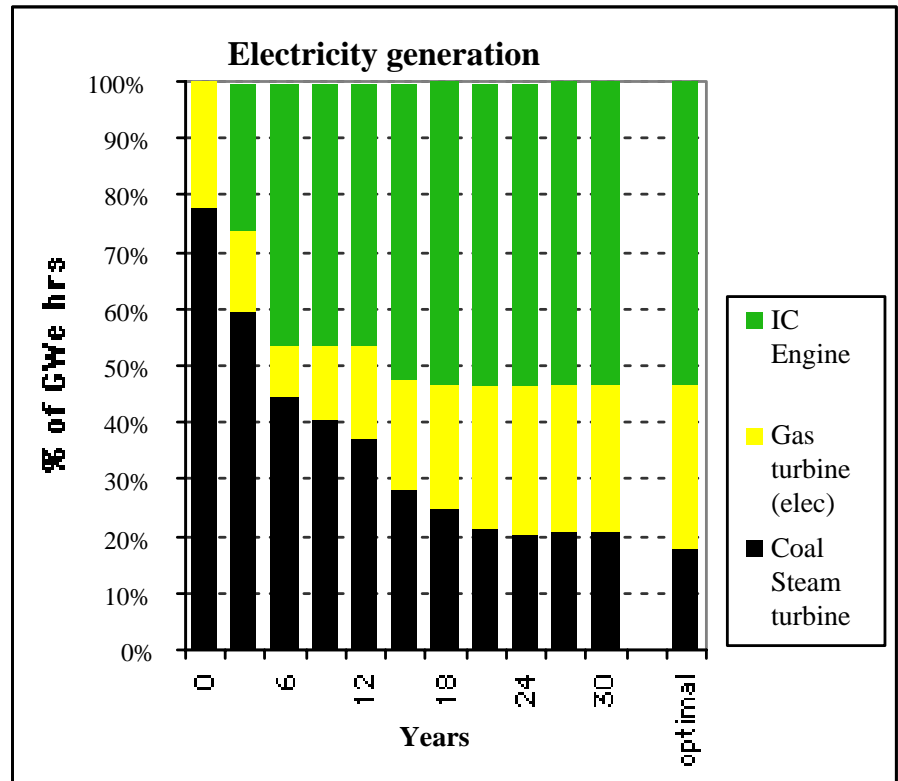
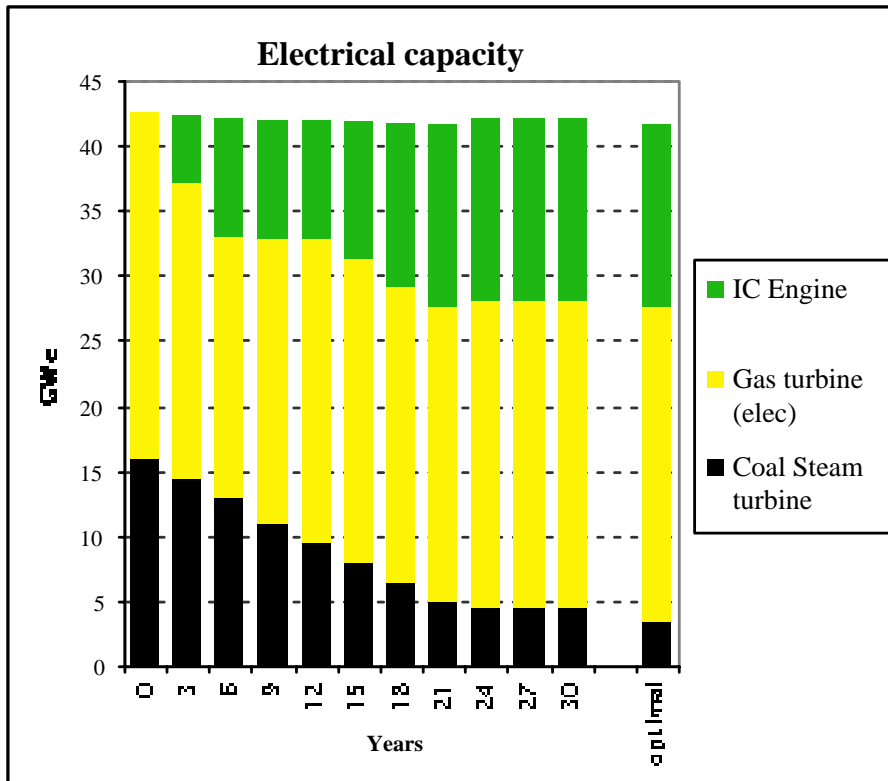


DG introduction within an existing system

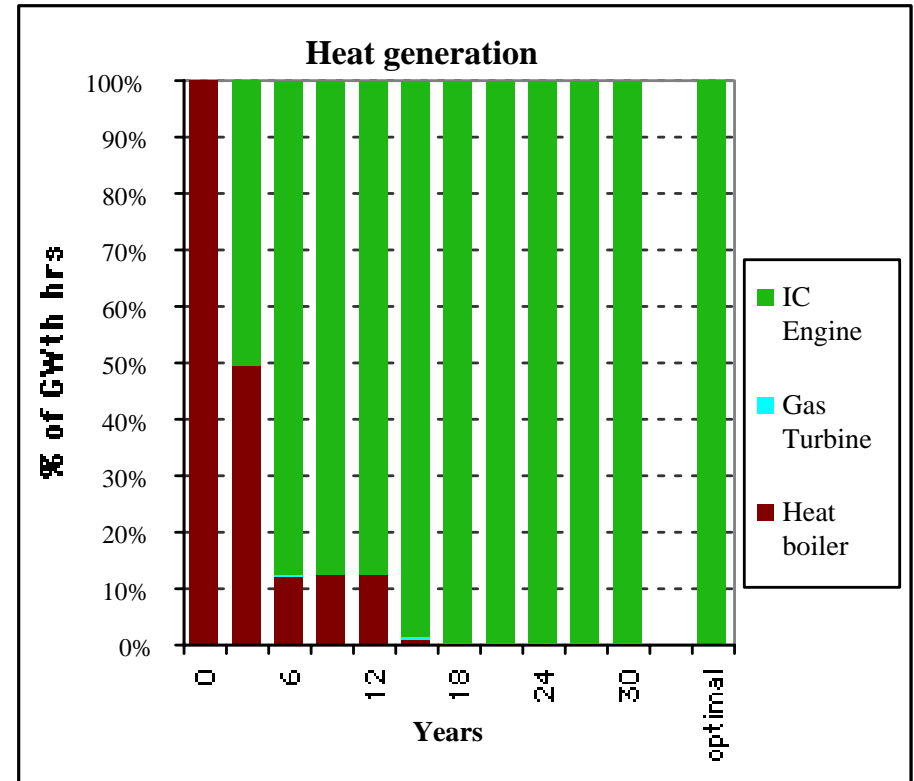
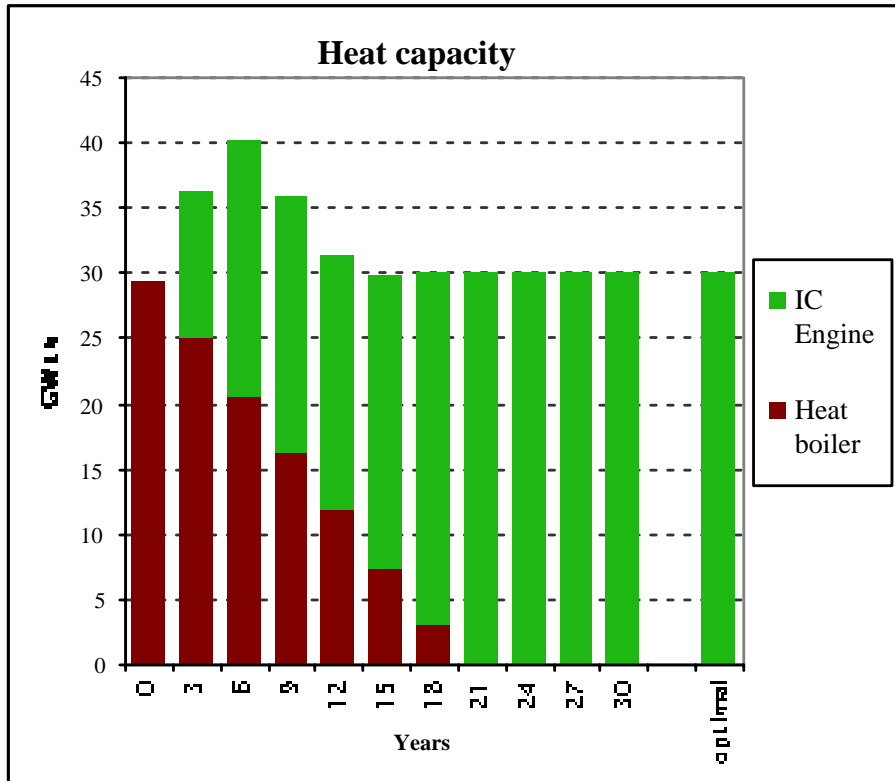
(Path dependence and stranded generation assets?)

- Run the model without DG: produce the initial technology mix
- Rerun the model in 3-year periods with technology retirements (and demand changes)
 - » Thus at any time (t), the existing plant mix will be: [original plants (t_0)] – [retirements ($t_3, t_6 \dots$)] + [new plant ($t_3, t_6 \dots$)] – [new plant retirement ($t_{\text{plant lifetime}}$)]
- Track the evolution of the energy supply mix
 - » Lowest cost DG is expected to be the new technology of choice
- Track the load factors of existing plant
 - » If investment in technically serviceable plant is not recovered, this is a stranded asset
- Track capacity additions of DG
 - » System evolution constraints?

System evolution (Florida) with DG introduction (Electricity demand)



System evolution (Florida) with DG introduction (Heat demand)



Existing technologies

(generation changes (GWhrs) from planned)

(Years)	Coal steam turbine	CCGT (elec)	Gas turbine (elec)	Heat boiler	Total
3-5	-59,457	985	-22,411	-180,660	-261,543
6-8	-97,781	1	-47,525	-377,338	-522,643
9-11	-70,517	1,085	-22,494	-278,986	-370,912
12-14	-49,791	971	-11,342	-196,573	-256,735
15-17	-57,058	-22	-2,279	-197,461	-256,821
18-20	-38,918	0	3,571	-127,327	-162,674
21-23	-18,264	0	2,985	8,798	-6,481
24-26	-7,318	0	0	0	-7,318
27-29	-3,375	0	0	0	-3,375
Total	-402,479	3,021	-99,495	-1,349,548	-1,848,501
% difference	-24%	+61%	-25%	-70%	-46%

Considerable under-utilization of existing plant - stranded assets

Number of new generation plant additions

years		3	6	9	12	15	18	21	24	27	30
Gas turbine (elec)	new plant	0	134	592	544	403	333	264	94	134	592
	hrs run	0	1600	924	1068	1254	1504	1698	1700	1698	1700
	retirals	0	0	0	0		0	0	0	134	592
IC engine	new plant	10439	7856	3	0	2711	4205	13185	7853	17	0
	hrs run	7884	7881	7884	7884	7742	6526	5897	6375	5895	6869
	retirals	0	0	0	0	0	0	10439	7856	3	0

- » Rapid but uneven deployment of DG
- » 8,000 DG units over three years, then 3 units over three years
- » But in Netherlands, maximum has been 2,000 units from 1993-1995
 - » Technical constraints on system?
 - » DG supplier issues?

Conclusions

- MILP cost optimization model developed to compare DG and conventional techs in integrated electricity and natural gas system
- A DG energy system architecture offers considerable benefits
 - » Around 25% cost savings depending on load variability
 - » Sensitivity analysis illustrates robustness of model results
 - » Overall gas usage reductions (~22%) - seasonal gas savings dependent on HPR matching
 - » CO₂ reductions: 24% relative to gas system ; 50% relative to coal/gas system
 - » Potential for SO₂ savings ; NO_x picture is more complex
- With existing plant (path dependency)
 - » System evolves to optimal configuration
 - » Stranded assets of existing plant
 - » Rapid but uneven deployment of DG raise system and suppliers feasibility issues

Robustness Implications of DG systems

Outline

- Introduction
- Historical Cases
- Reliability Assessment
- Future Work
- Conclusions

Introduction

- Electric power systems are targets in violent conflict which complicates the planning of systems
- Hypothesis: Distributed co-generation will be more robust under adverse conditions than centralized systems
- DG should result in less reliance on a small number of large generators and be impacted less by damage to the T&D system
- Combination of economic analysis of distributed co-generation and engineering modeling of reliability of electric power systems in conflict areas

Bosnia and Lebanon

- Significant damage to all levels of the electricity sector
- The cost to rebuild is significantly less than the cost of constructing all new facilities
- Indicates a level of vulnerability since a small amount of damage can be sufficient to disable system components
- The electricity sector is the single largest component in Lebanon's post-conflict reconstruction and development efforts, accounting for about a quarter of expenditures.
- Natural gas system in Bosnia also affected.

Conflict is not a Hurricane

Planning requirements may be similar to those for extreme weather events, but there are significant differences:

- Persistence of Adverse Conditions
- Length of Outage
- Scope of Damage
- Coordination of Attack

Reliability Assessment

- Potential Reliability Impacts of Distributed Generation
 - » Reliability implications of distributed generation depend, in part, on whether distributed units are connected to the grid
 - » Distributed generation reduces the reliance on a small number of large generators and on the T&D system
 - » Conversely, the reliability of the grid can compensate for the loss of individual DG units
 - » DG raises the issue of grid inter-connection and changes in how electricity grids are normally operated. Active research in this area, specifically in the realm of control technologies.

Monte Carlo Reliability Simulation

- Generating Capacity Adequacy Assessment
- Track generator status through time and compare total available capacity to demand on an hourly basis
- A large number of years of operation are simulated (up to 2500 years)
- Loss of Load Expectation (hours/year) and Loss of Energy Expectation (MWh/year) are calculated
- Model results match Billinton and Li.

Comparison of Model Results

Index	Billinton and Li	Our Model
LOLE (hr/yr.)	9.4	9.6
LOEE (MWh/yr.)	1200	1180

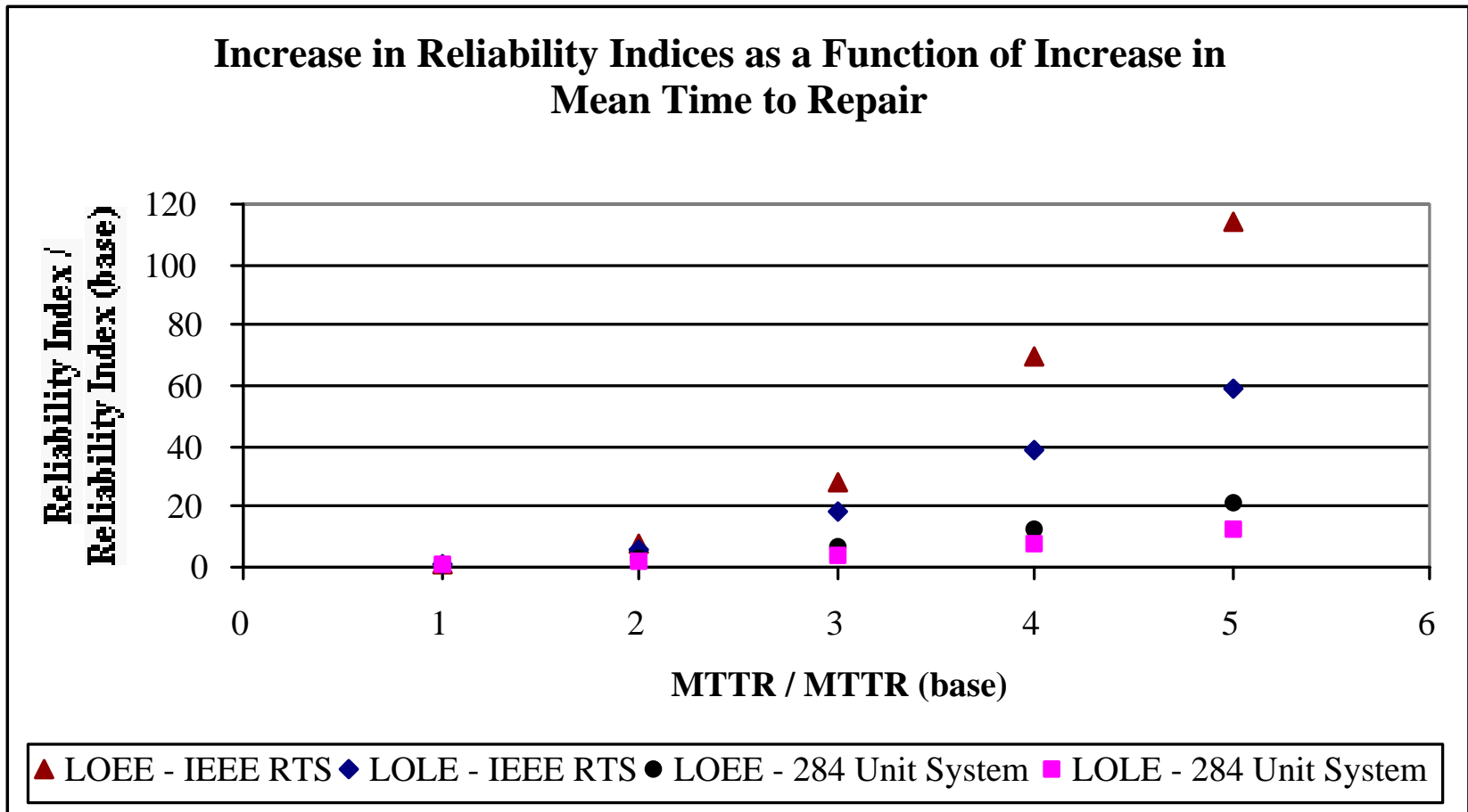
Simulation of Conflict Impacts

- Two system configurations simulated
 - » The IEEE Reliability Test System consisting of 32 generators ranging in size from 12 to 400 MW (Total Capacity = 3405 MW)
 - » A system consisting of 284 units, each unit is 12 MW
- Increase in the Mean Time to Repair (MTTR) was chosen as an initial proxy for the impacts of conflict on electricity systems
- For both systems, the MTTR of all units was increased from its base case (by 2, 3, 4, and 5 times the base) and the simulation was run to determine the LOLE and LOEE

Simulation Results

- Centralized system is more sensitive to changes in the Mean Time to Repair
- Distributed system up to five times less sensitive than centralized system (over the range of MTTR considered)
- Of the two reliability indices, the Loss of Energy Expectation (LOEE) is more sensitive to changes in repair time

Simulation Results (cont.)



Current and Future Work

- Switch to State Sampling Method for generating capacity adequacy assessment for improved computational performance, especially with systems that have a large number of generators
- Coupling of engineering analysis and economic analysis to include reliability in cost model. Capital cost model developed. Long run average operating cost determined by dispatch of units in reliability model.
- Inclusion of network effects (transmission system)
- Assessment of natural gas delivery infrastructure

Conclusions

- Historical record indicates the need to specifically consider deliberate attacks against energy systems in certain case
- Distributed generation holds the promise of improved reliability in comparison to centralized systems under these circumstances
- Distributed co-generation already compares favorably with centralized generation under certain conditions
- Results of preliminary Monte Carlo reliability simulation supports hypothesis.