Computational Needs and High Performance Computing in Power System Operation and Planning

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Evolution of Computing Power

1 flop/s = one floating-point operation (addition or multiplication) per second
mega (M) = 10^6, giga (G) = 10^9, tera (T) = 10^{12}, peta (P) = 10^{15}, exa E) = 10^{18}

In 2010…

Cell phone
1 Gflop/s

Laptop
20 Gflop/s

Workstation
1 Tflop/s

HPC
20 Tflop/s

#1 supercomputer
2.3 Pflop/s

…would have been the #1 supercomputer back in…

Cray X-MP/48
941 Mflop/s
1984

NEC SX-3/44R
23.2 Gflop/s
1990

Intel ASCI Red
1.338 Tflop/s
1997

Earth Simulator
35.86 Tflop/s
2002

Evolution of Computing Power

...the performance of the #1 supercomputer of 2010...

#1 supercomputer
1 Pflop/s

...could be available as

HPC
1 Pflop/s
2018

How do we get here?

Workstation
1 Pflop/s
2023

Laptop
1 Pflop/s
2030

Cell phone
1 Pflop/s
2036

Definition

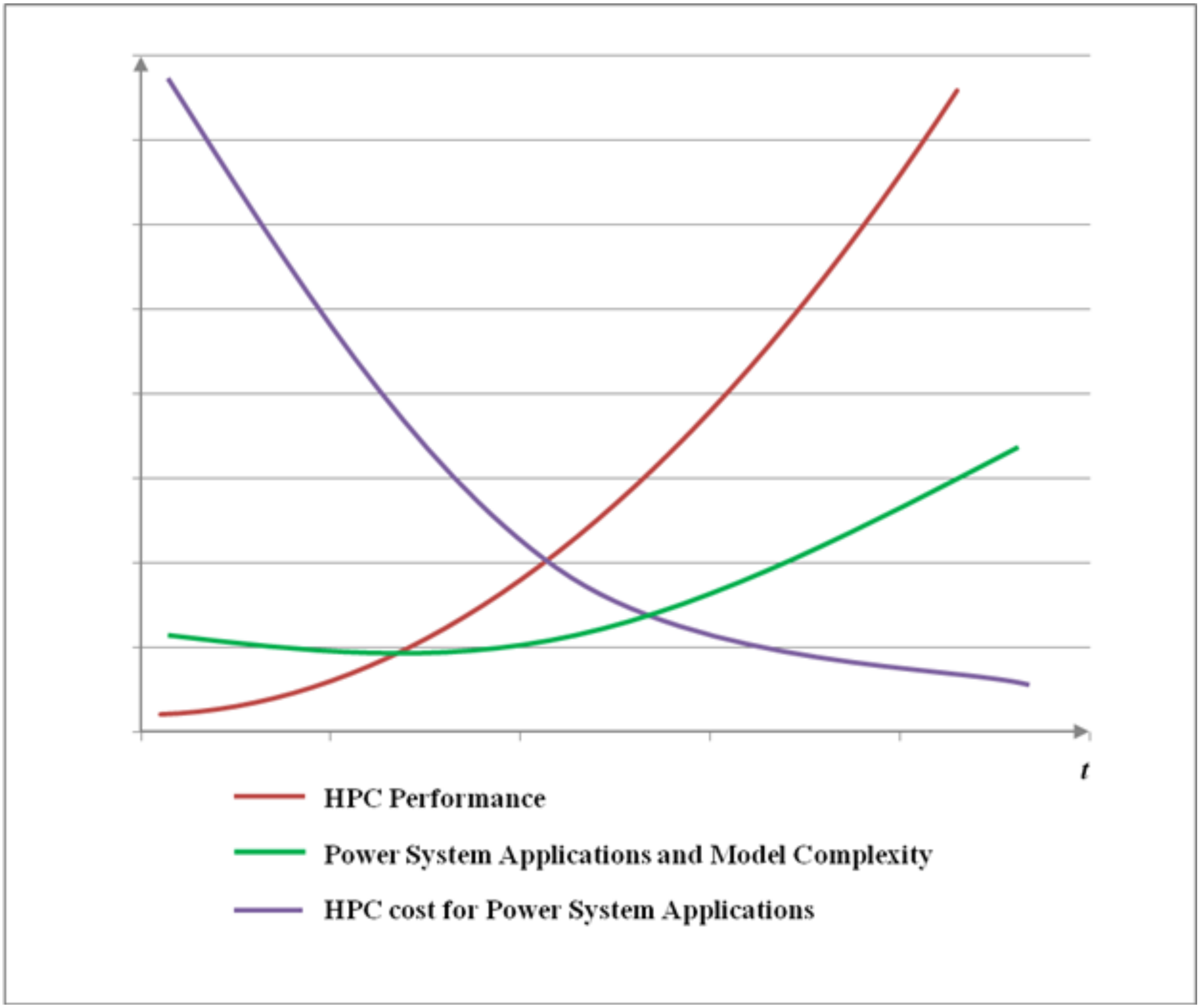
- High-performance computing (HPC) is the use of super computers and parallel processing techniques for solving complex computational problems. HPC technology focuses on developing parallel processing algorithms and systems by incorporating both administration and parallel computational techniques.

techopedia

Why HPC?

- The size
- The complexity of the power grid today and nearest future:
  - Distributed resources
  - Renewable resources
  - High volatility
  - Microgrids
  - Controls
- The Data
- The evolution of computing – the cost of HPC is dropping

Why HPC?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HPC Performance
Power System Applications and Model Complexity
HPC cost for Power System Applications

Power Flow Model Today

PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E TUE, JUN 11 2013 10:08

	BUSES	PLANTS	MACHINES	WIND MACHINES	MACHINE OWNERS
TOTAL	64287	6736	8466	23	8616
MAXIMUM	150000	26840	33050	560	66100

	S H U N T S			MULTI-SECTION LINE	
	FIXED	SWITCHED	LOADS	GROUPINGS	SECTIONS
TOTAL	2268	5785	34984	39	82
MAXIMUM	150000	10580	300000	3710	9260

		T R A N S F O R M E R S			
	BRANCHES	TWO-WINDING	THREE-WINDING	ZERO IMPEDANCE	BRANCH OWNERS
TOTAL	82427	23941	1955	3016	90824
MAXIMUM	300000	60000	15000	7500	600000

	AREAS	ZONES	OWNERS	TRANSFERS	MUTUALS
TOTAL	139	832	340	0	0
MAXIMUM	1200	9999	1200	2000	4000

	2-TERM. DC	N-TERM. DC	VSC DC	FACTS DEVICES	GNE DEVICES
TOTAL	38	0	0	1	0
MAXIMUM	50	20	40	250	40

New Opportunities

- Current studies are always a compromise between confidence and time
- Large margins to account for:
  - Uncertainty
  - Not enough time to run all scenarios needed
  - No systematic way of selecting scenarios
- HPC will allow for higher confidence and save costs on lowering margins
- Reformulation of conventional tasks with new mathematical models is impossible with traditional computing environments

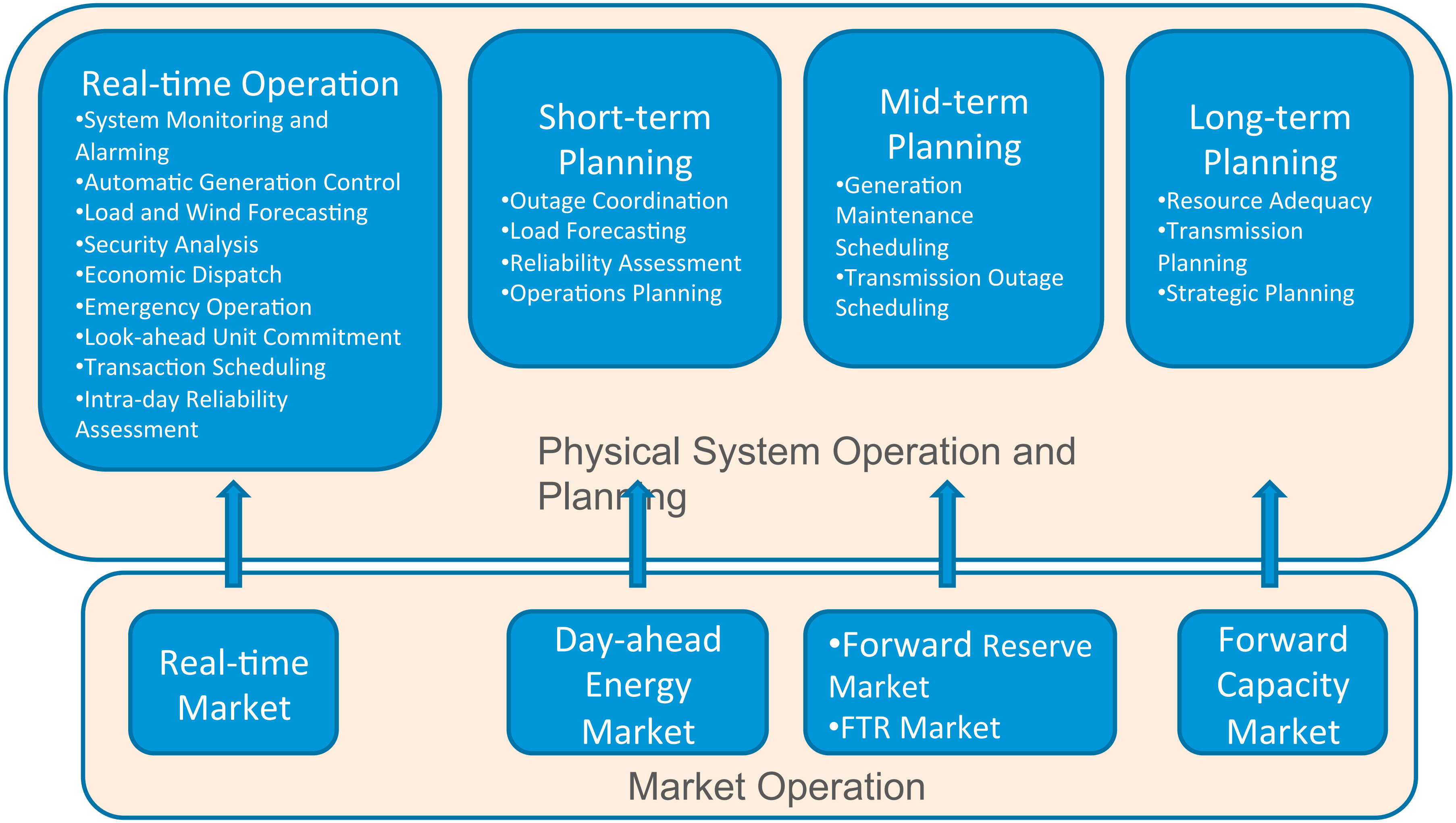
Three Primary Areas of Responsibility

Reliability

Markets

Planning

Market and System Operation



Possible Applications

- Power System Simulation
- Long-term and strategic planning
- Short-term planning
- Market Operation
- Market Simulation
- Real time monitoring
- Control
- R&D

Power System Simulation

- Simulation is a fundamental element in power grid operations
- Complexity:
  - Nonlinear, non-convex functions
  - Discrete and integer variables
  - Ill-behaved characteristics
  - Hundreds of Thousands of differential and algebraic equations
- Large volume of data
- Simulation is slow and takes long time
- Need high performance computing techniques and advanced computing hardware

Transmission Planning

Reliability Planning:

- Long range time horizon (1 to 10 years)
- Transmission planning studies need to consider
  - Different transmission plan alternatives/topologies
  - Different load levels (peak, shoulder and light load)
  - Different stress directions (generation dispatch) at each load level
  - Thousands of contingencies (N-1)
  - 2nd level contingencies N-1-1
- Steady state analysis: thermal and voltage analysis

Transmission Planning

- Dynamic stability: time domain simulation
  - Need to model all dynamic devices (generators, exciters, governors, power system stabilizer, HVDC, power electronics, relays, etc)
  - Tens of thousands of nonlinear ODEs with time steps in milliseconds and over 50,000 nonlinear algebraic equations
  - One twenty seconds time domain simulation normally takes 20 minutes of CPU time

Transmission Planning

- Southeast Massachusetts and Rhode Island assessment
  - Needs Assessment
    - 36 power flow case, 295 first level contingencies, 2122 second level contingency
    - One N-1-1 AC analysis takes about six minute
    - 36*295*6 = 63,720 minutes = 1,062 hours
  - Solution Study: at least five different alternatives

- Maine Power Reliability Program (MPRP) stability study
  - 11 power flow cases, 477 dynamic contingencies
  - One twenty-second dynamic simulation takes about 20 minutes in PSSE
  - 11*477*20 = 104,940 minutes = 1,749 hours

Transmission Planning – Economic Planning

- Open stakeholder process to study alternative future system scenarios such as:
  - Large-scale integration of renewable resources in the 20-year timeframe
  - Interregional analysis of increased transfer limits conducted by the Joint ISO/RTO Planning Committee
  - Retirement of coal and oil units
  - Strategic studies
  - Production costing
- Metrics:
  - Economics: Production Cost, LSE Energy Cost, LMP, Congestion
  - Environmental emissions (SO_2, NO_x, etc)
  - Fuel consumption / energy by fuel type

Operations Planning

- Shorter time horizon (up to 1 year)

- Operations planning studies need to consider
  - Line outage condition
  - Different load levels (peak, shoulder and light load)
  - Different stress conditions (generation dispatch) at each load level
  - Hundreds of contingencies (N-1)

- Close to two hundred stability operating guides

Resource Adequacy

- Probabilistic study using Monte Carlo simulation to determine installed capacity requirements, tie benefit, etc
- Typically users run 1000 replication years, which takes around 10 hours
- Number of sensitivities
- Each replication is independent and can be parallelized
- Transmission Model

The Benefits of HPC for Planning

- Produce more efficient solutions
- Produce more robust solutions
- Allow engineers to spend more time on "engineering" rather than data preparation, processing and waiting.
- Allow solving problems that otherwise impossible
- More efficient use of the infrastructure
- Avoid compromise due to lack of time

On-line Security Analysis

- Real time operation needs to calculate the system security and stability limits timely and accurately to enhance the operational decision making and reduce the risk of cascading failure
- On-line contingency analysis, voltage stability analysis and dynamic stability analysis
- Automatic preventive control and corrective control recommendations
- Contingency screening and ranking techniques
- Time domain simulation

Power System Operation

- Preventive vs Corrective paradigm
- The need for superfast computation
- Faster than real time simulation
- Early warning systems
- Ability to use new controls
- Decision support systems
- Online monitoring of system resiliency
- Wide area special protection systems

Market Operation

- The need for high performance in Day Ahead market due to gas dependencies
- Use of stochastic programming to deal with uncertainties
- Market simulation
- Multi-stage decision support and pricing
- Market coordination

“Big Data”

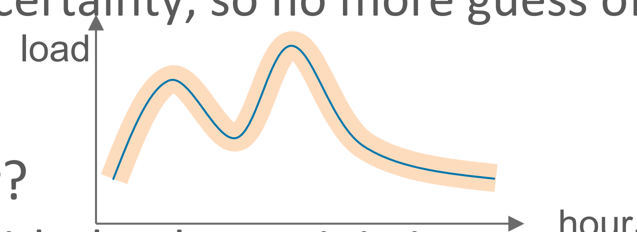
- Explosion of data available at the control centers
- Phasor Measurement Units (PMU)
- Data mining applications for event detection
- Intelligent alarming
- Nation-wide and regional repositories for situational awareness

Supercomputers

- There is not enough statistics to validate system planning results
- Need for massive amount of calculation to periodically validate assumptions and engineering decisions
- May take years to run
- Simulation of future alternative grid architectures
- Simulation of interactions with other infrastructures on national or regional scale

Evaluation of Robust Unit Commitment

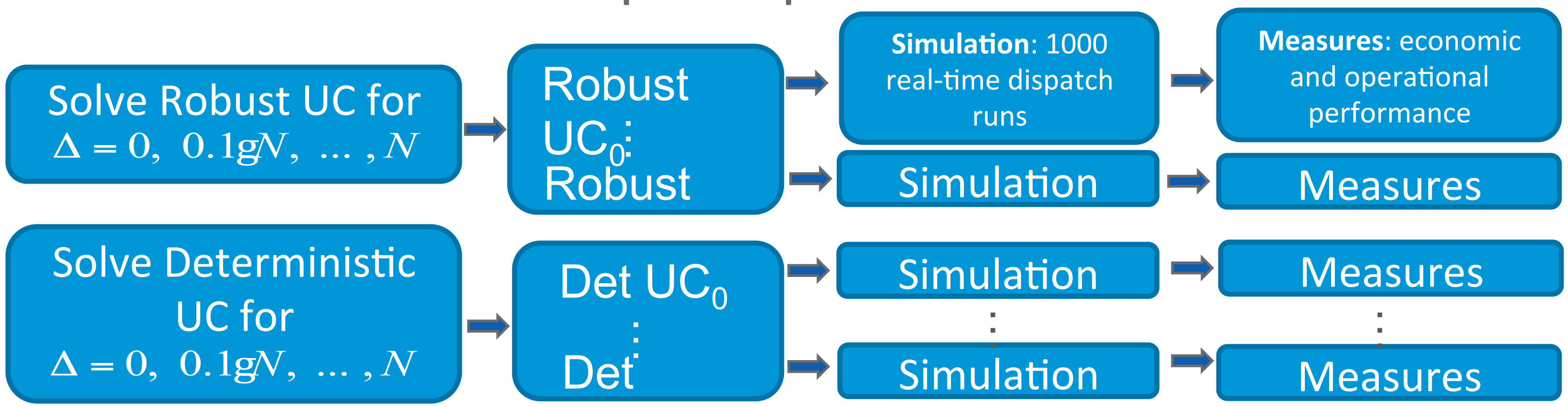
- Why consider robust unit commitment (UC)?
  - Increasing number of renewable and demand response resources
- What is robust unit commitment?
  - Takes into account a range of the uncertainty, rather than a point forecast as in the deterministic reliability UC process.
  - Guarantees the feasibility of the system.
  - Requires mild information of uncertainty, so no more guess of the probability distribution.



- Is robust unit commitment better?
  - Compare the robust approach with the deterministic approach by running a large number of Monte Carlo simulations.
  - Evaluate the operational and economic benefits
  - Identify the optimal conservatism level of the robust approach.

Prior to the *hpc4energy* collaboration

- Simulate the real-time dispatch process



- Codes in use
  - Implemented in GAMS using CPLEX 12.1.0 solver on a PC laptop with an Intel Core (TM) 2Duo 2.50GHz CPU and 3GB memory.
  - Take about 30 minutes to solve a robust UC problem.
  - Take about 15 seconds to solve a dispatch problem in the simulation.
  - 1600 robust UC runs × 1 M dispatch runs = 761 years

Current Results

- Solve robust UC problems
  - Multiple robust problems can be solved at the same time.

    1 robust UC run per core
    10 cores per computer node
    5 nodes per scenario
    32 scenarios
    = 1600 robust UC runs

> • Time to solve 1600 robust UC problems decreased from 800 hrs to 30 minutes
> • Allow a more comprehensive evaluation

- Select scenarios for simulations
  - Number of historical data is small
  - Use the "cluster method" to create samples for simulations

Value added by LLNL *hpc4energy* collaboration

- HPC can efficiently run millions of simulations, which is impossible to be achieved by the computing capability of ISO NE.
- Allows more flexible evaluation designs.
- Simulations yield more statistically significant results.
- Enable ISO NE to perform more accurate and more comprehensive evaluation of the robust UC.

Cloud

Internal Grid Computing Environment

- Simulation tool:
  - Siemens PSSE
  - PowerGem's TARA
  - GE MARS
- Grid computing tool:
  - Enfuzion
- Configuration:
  - Control computer: one (psseroot)
  - Worker computers: four, a total of 40 processors
  - User computers: individual's desktops
- Users need to prepare Enfuzion RUN file and submit for execution

Issues with today's Internal Environment

- Long wait time due to the increasing number of users and workload

- Scalability:
  - Maximum capacity of the system is reached
  - Adding additional resources takes time
  - Hard to estimate the peak demand and average business computing needs and purchase the IT infrastructure accordingly

Objectives of the PoC Cloud Computing Project

- Get hands-on experience and knowledge of the cloud computing technology
- Experiment deploying power system application in the cloud environment
- Benchmark performance between cloud run and internal run
- Estimate cloud infrastructure usage cost

Amazon EC2 Cloud Computing

- Proof of Concept project with Cycle Computing
- Amazon EC2 to provide the cluster grid
- On-demand creation and use of high performance computing environments as a metered, pay for use, service
  - Reserved instance pricing
  - On-demand instance pricing
  - Spot instance pricing
- Condor scheduler technology for load distribution and CycleServer for monitoring progress of workload and job scheduling
- Encryption schemes to secure data at various stages of the computation pipeline.

Engineering Application

- TARA - Transmission Adequacy & Reliability Assessment

- Software registration issue
  - Special cloud license

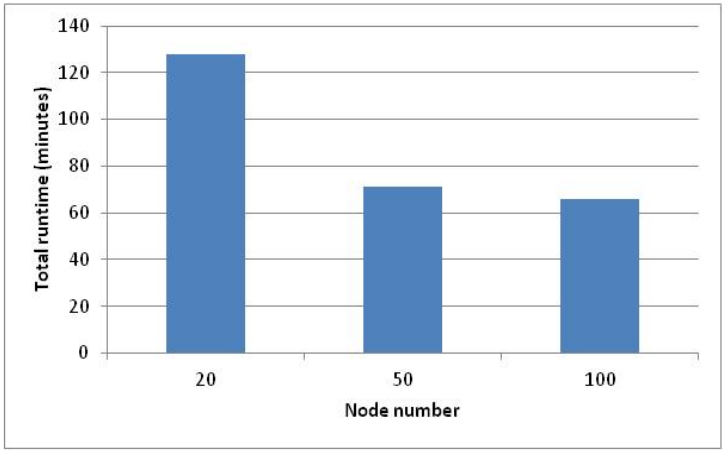
- Engineering study
  - AC N-1-1 contingency analysis
  - Twenty five power flow cases with 164 line-outs, a total of 4100 combinations (jobs)

Test 1

- Smaller power flow case (5MB) with equivalent of all areas outside of NPCC
  - > 340 hours on individual's desktop
  - > 8 hours over the internal Enfuzion environment
- Amazon EC2
  - C1.xlarge instance: 8 cores, 7GB RAM
  - Setup time of computing nodes: 10~20 minutes

Cost:

- 20 * 3 hours * $0.20/hr = $ 12
- 50 * 2 hours * $0.20/hr = $ 20
- 100 * 2 hours * $0.20/hr = $ 40



Test 2 & 3

- Full power flow case without equivalent (23 MB)
  - > 1700 hours on individual's laptop
  - > 40 hours over the internal Enfuzion environment
- Amazon EC2
  - C1.xlarge instance: 8 cores, 7GB RAM
  - 150 computing nodes
  - 90 minutes to finish with cost about $60
- Encryption enabled (AES-256)
  - S3 server side encryption on all data transfer to and from S3 storage
  - Encryption on shared file system between Linux scheduler and windows execution nodes
- The same case as in test 2 was run in test 3
- No performance impact was noticed due to encryption

Challenges in Adopting HPC

- Besides “embarrassingly” parallel applications (like contingency analysis), current software is not created for HPC.
- Major computational engines have to be rewritten for parallel execution
- New class of decomposition techniques for solving optimization problems, ADE, etc.
- New class of algorithms and software has to be developed for using new technologies like GPU
- Vendor licensing