Benchmarking Software for Power Systems with Retiring Power Plants and Wind Power Plants

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*Work done as NETSS PhD intern, summer 2018

Outline

- As basic as it gets: How to operate power grids with new generation mix reliably and efficiently? Which software?
- Value of data-enabled software?
- Challenge problem at FERC Conference 2019-recap*
- Solution to the challenge problem stated at FERC conference 2019 (IEEE 14 node system)
- Challenge problem for FERC conference 2021—continuing!
- Lessons learned and recommendations

* *Ilic, M. Ten Years Later: Rethinking Principles of Smart Architectures and Data-enabled Software, FERC Conf 2019*

Basic challenge problem for software to operate changing electric power systems

- Given predicted demand pattern for day ahead
- Given retiring power plants and wind power plants deployed
- Schedule existing resources to optimize daily fuel cost so that
- Power is deliverable (AC power flow solved, thermal and voltage limits) and ramp rate limits are accounted for
- Find minimal load that must be shed to ensure the problem is solved
- Find the most critical constraints limiting delivery
- Compute reserve requirements so that during (N-1)/(N-2) contingencies power can be delivered
- Assess economic impacts on generation and demand, and MS

Challenge problem stated at FERC Conference 2019

- Can one do better than using **Dynamic Monitoring and Decision Systems (DyMonDS) operating paradigm?**
- **Three basic steps**
- Predicted future prices communicated to the end users; or collected/learned by the end users
- Distributed decision making by the end users to create physically implementable bid functions (using MPC-look ahead); **levelized cost bid functions**
- Minimally coordinated by solving AC OPF; physically implementable/(N-1)/(N-2) secure
- Computations on-line for DAM/RTM

The challenge of reliable/resilient operations

❖HV IEEE 14 bus system

--Generator 1 is a large coal unit of 250 MW. But, for the purposes of reliability, 120 MW of its capacity is set aside, making only about 232 MW available for operations

--Generator 2 is a dirty expensive unit which has been completely

decommissioned and has been replaced with an uncontrolled wind farm, whose patterns can only be predicted to desired levels of accuracy.

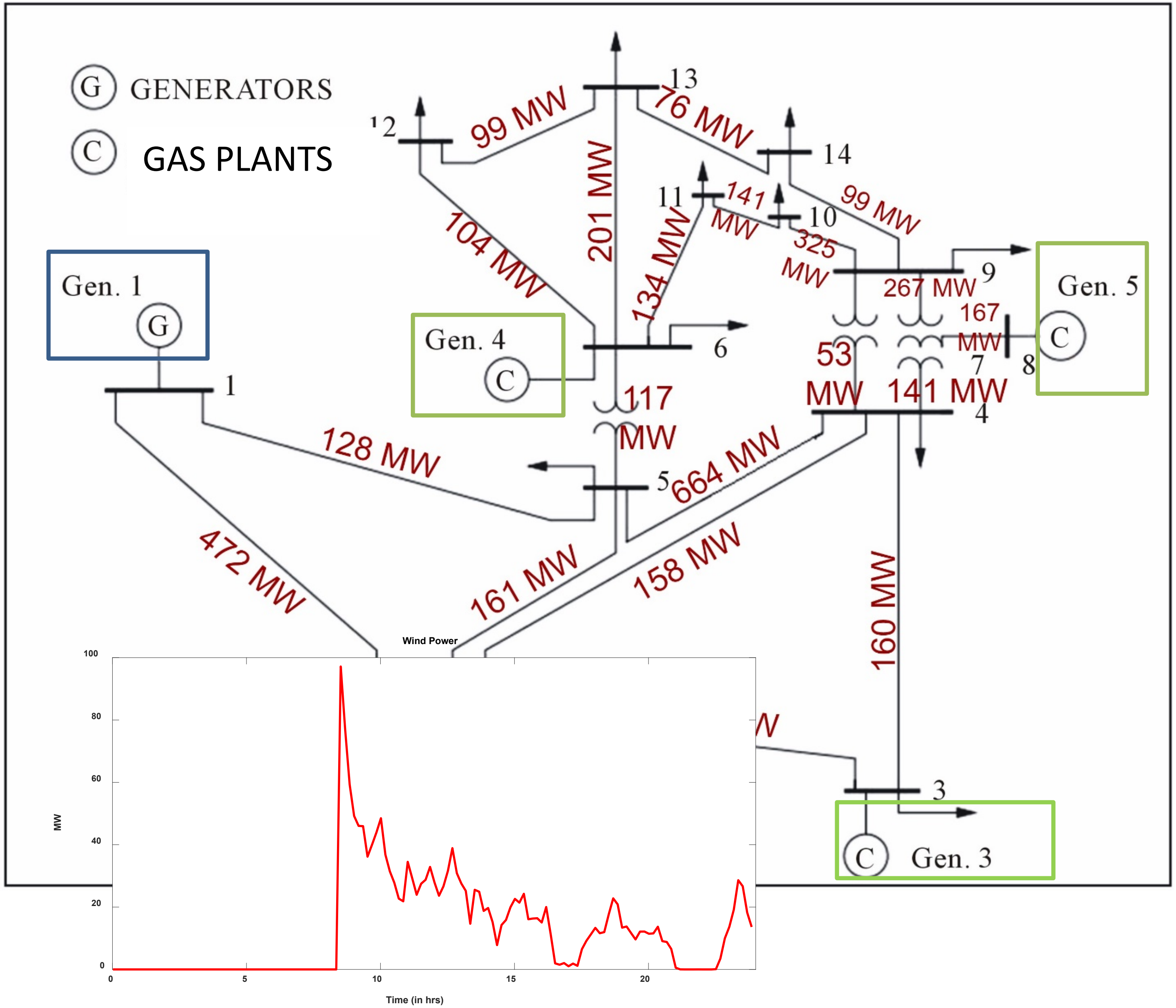
--Generators at locations 3, 6 and 8 are expensive as well and

are thus decommissioned, replacing them with DERs of 20 MW

capacity each to provide voltage support in times of need.

IEEE 14-bus test system

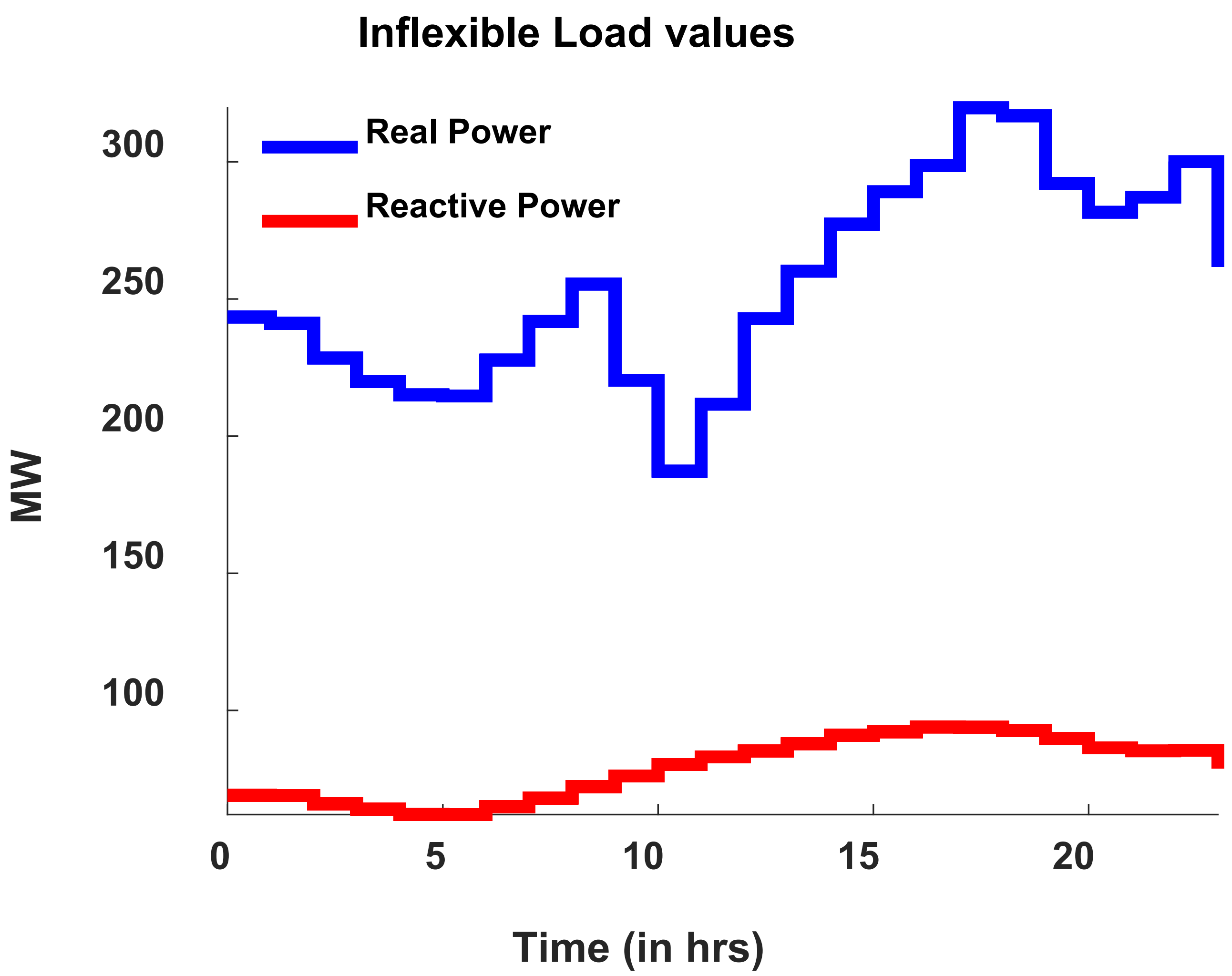
Gen 1:
Nuclear plant
Slowest and cheapest generator:
RR- 30% of capacity
Capacity – 352 MW
20 $/MWhr



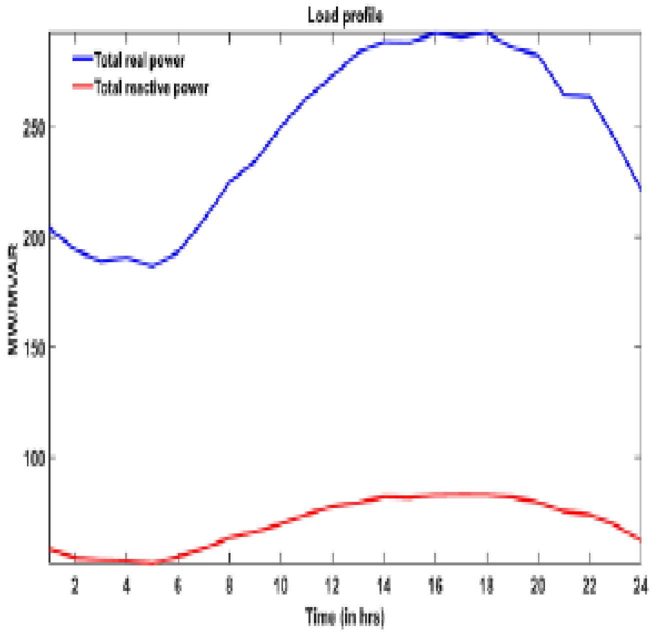
Gen 2:
Dirty generator:
RR-40% of capacity
Capacity – 150 MW
30 $/MWhr

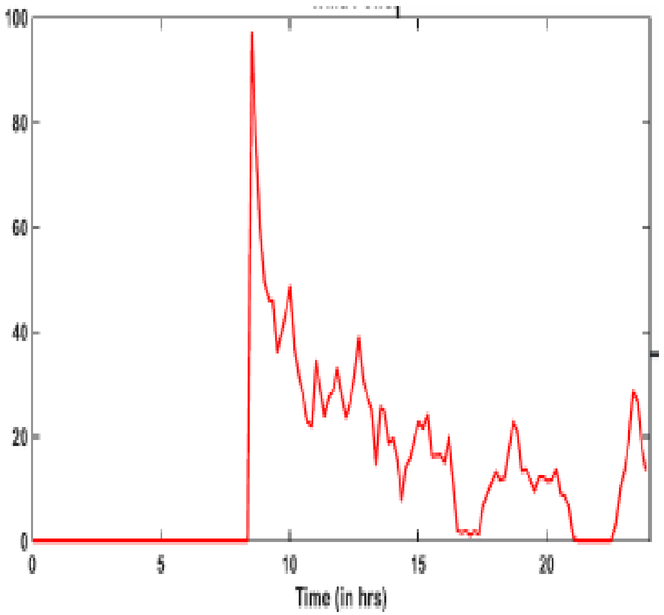
Gens 3,4 and 5:
Dirty, Expensive and
RR-50% of capacity
Capacity – total of 300 MW.
40 $/MWhr

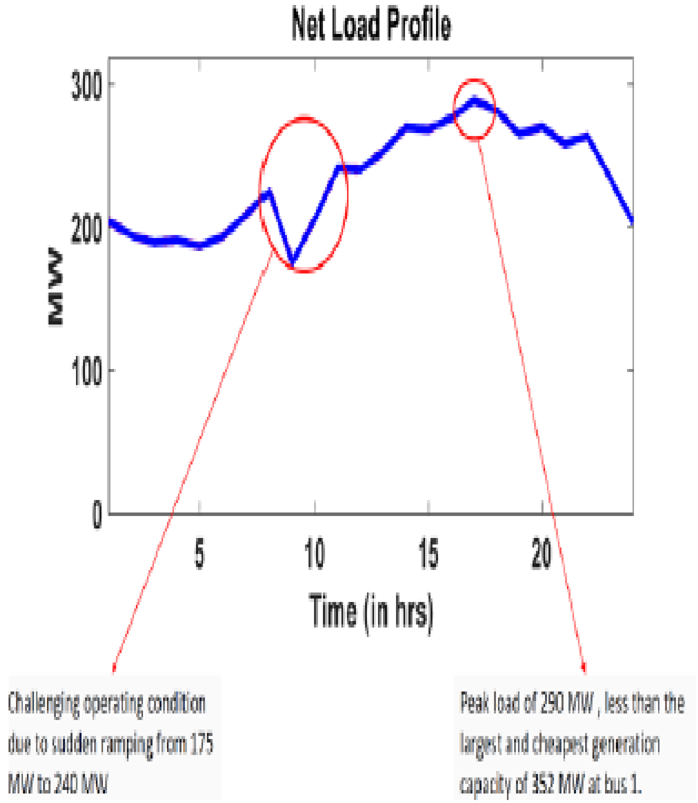
Load profile



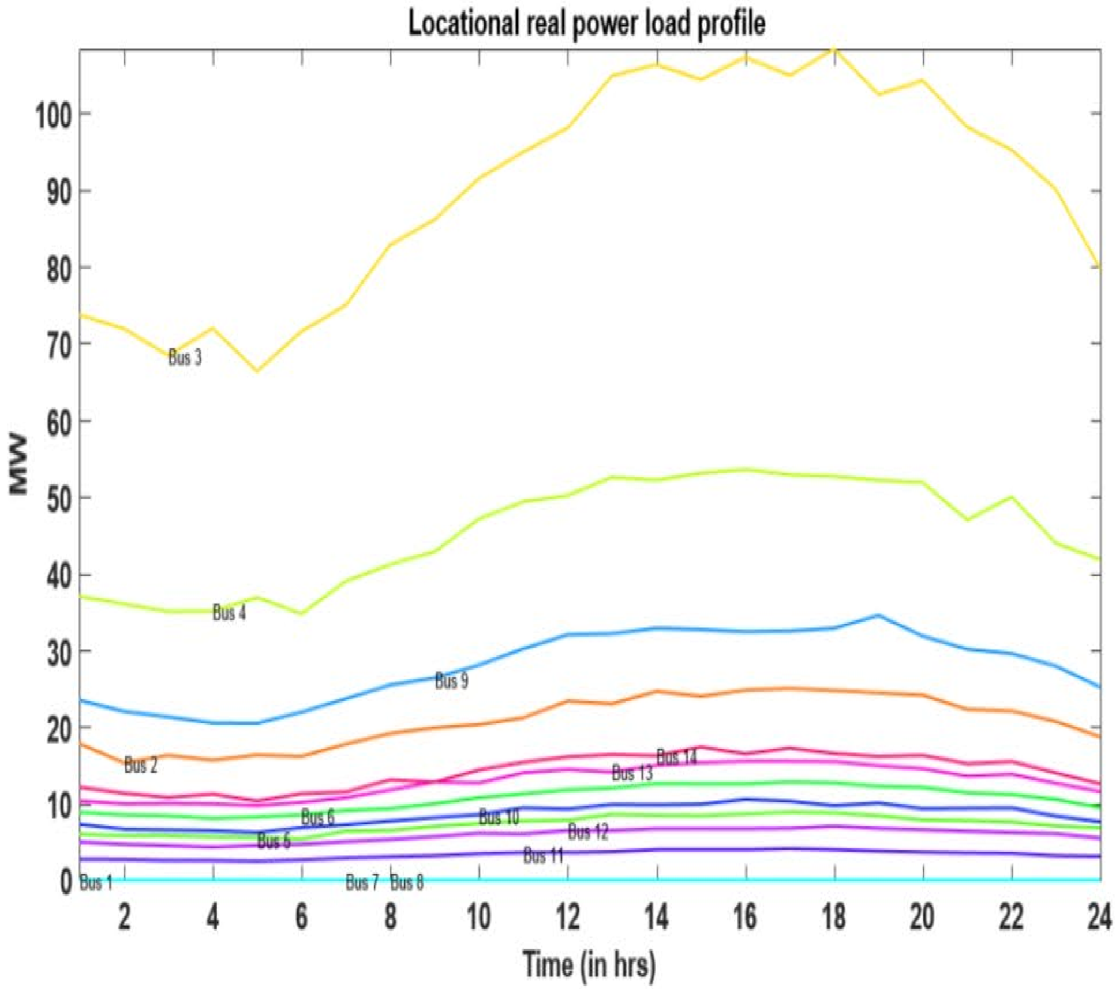
Net demand

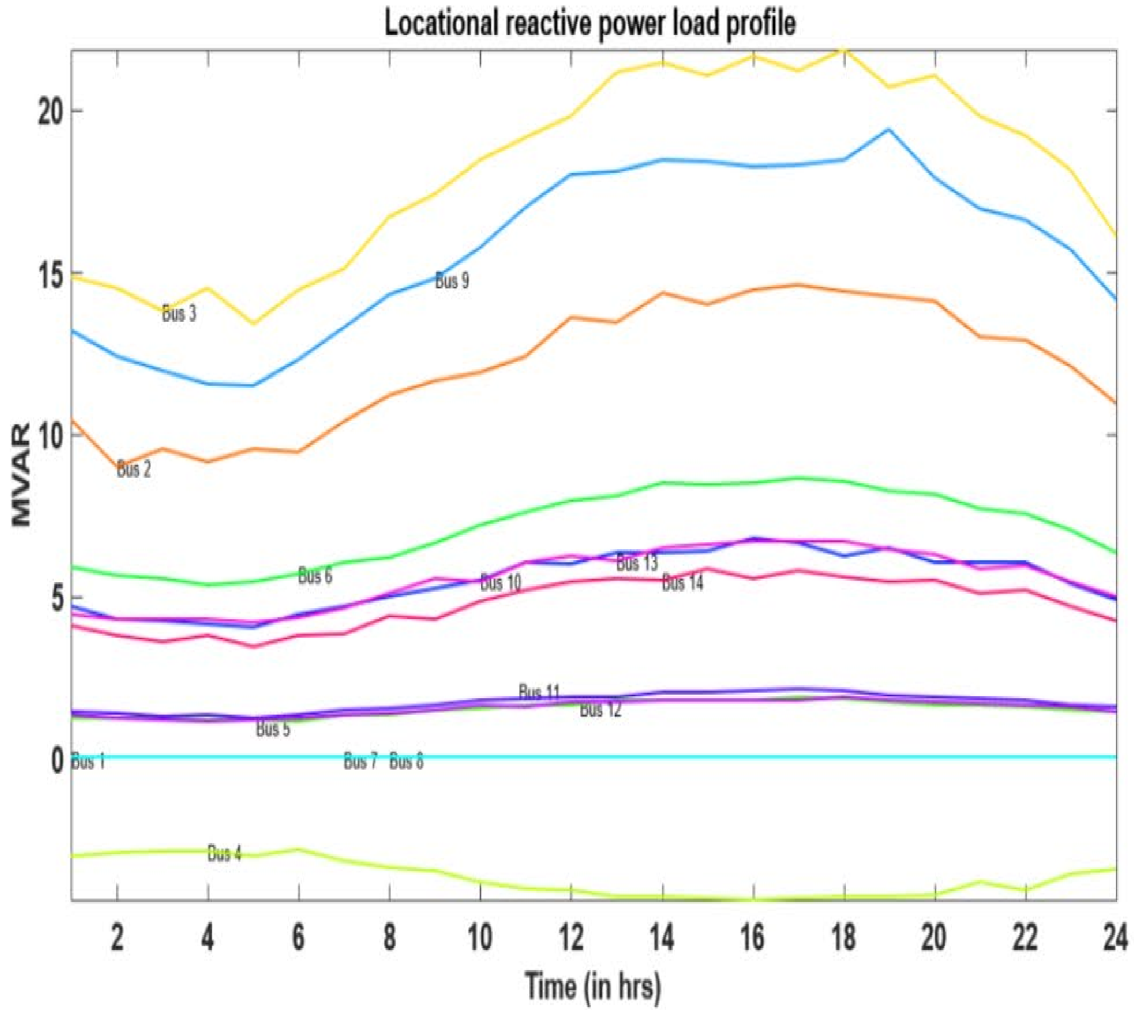

Load profile
Total real power
Total reactive power
MW/MVAR
Time (in hrs)


Time (in hrs)

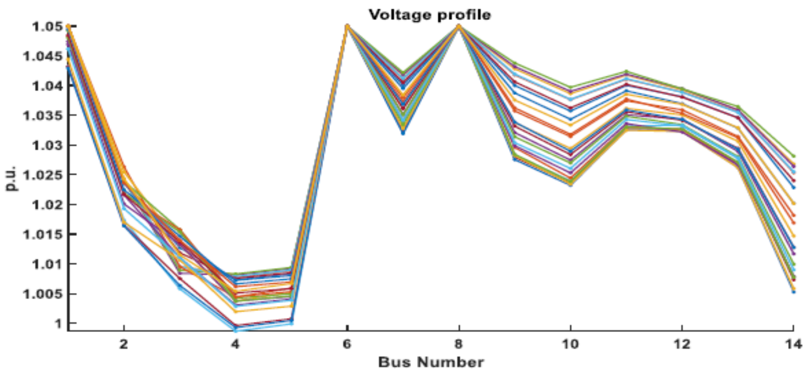

Net Load Profile
MW
Time (in hrs)
Challenging operating condition due to sudden ramping from 175 MW to 240 MW
Peak load of 290 MW , less than the largest and cheapest generation capacity of 352 MW at bus 1.

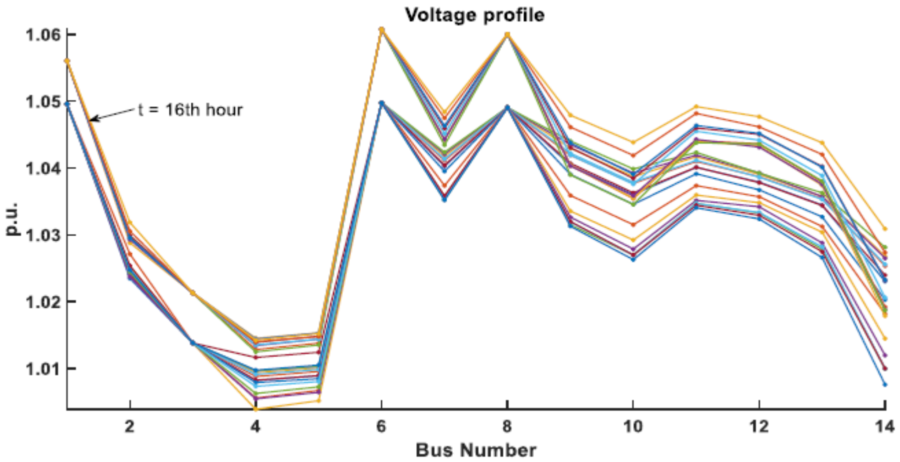
Locational distribution of system demand-Delivery problem!

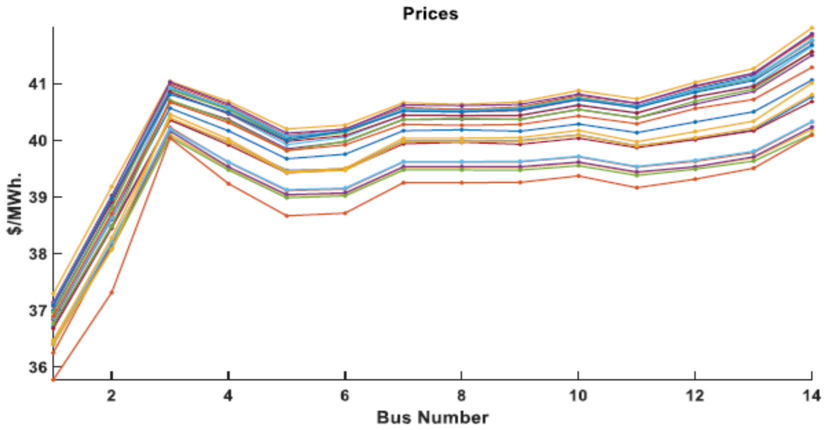


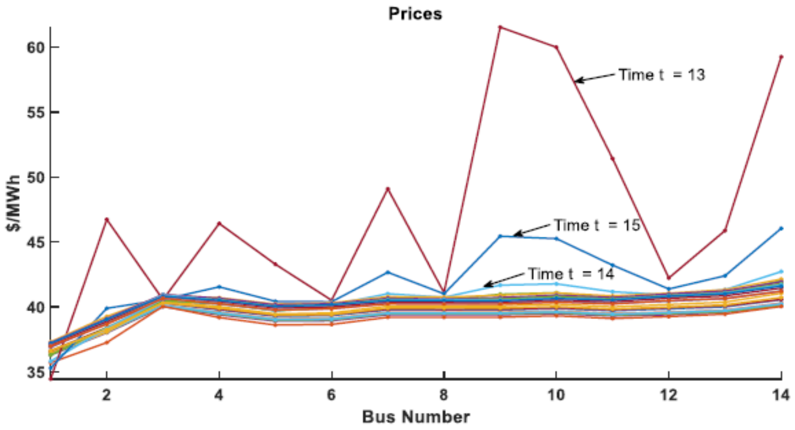


Effect of voltage optimization on LMPs

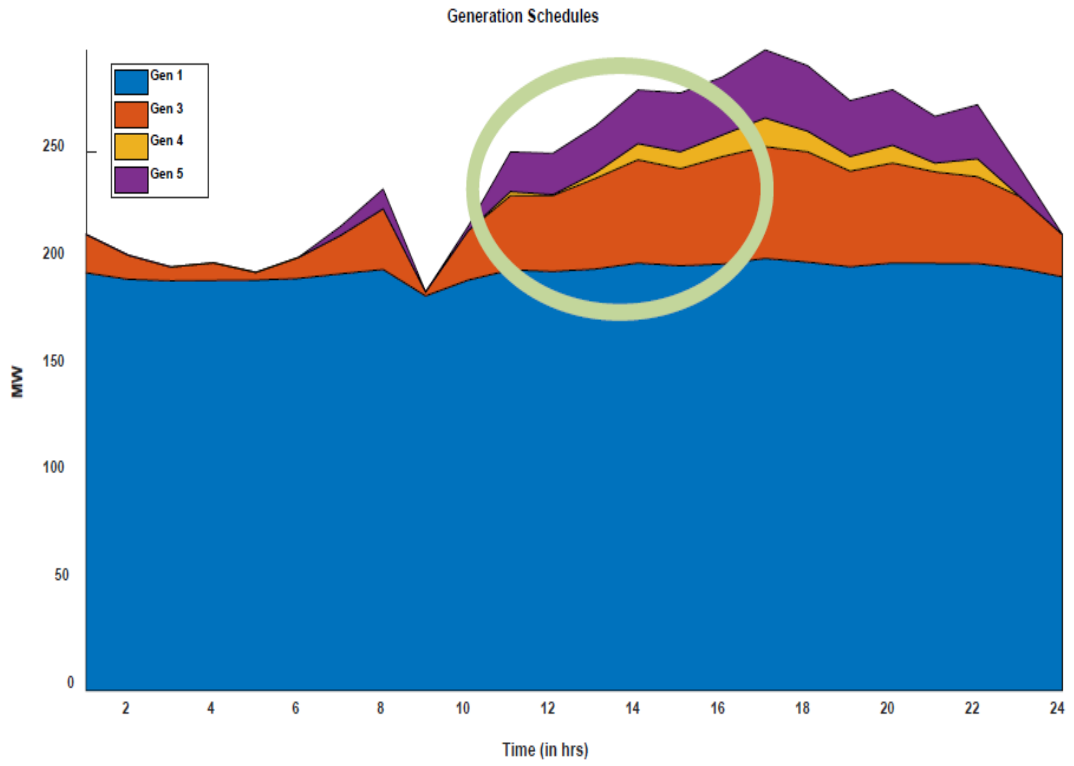


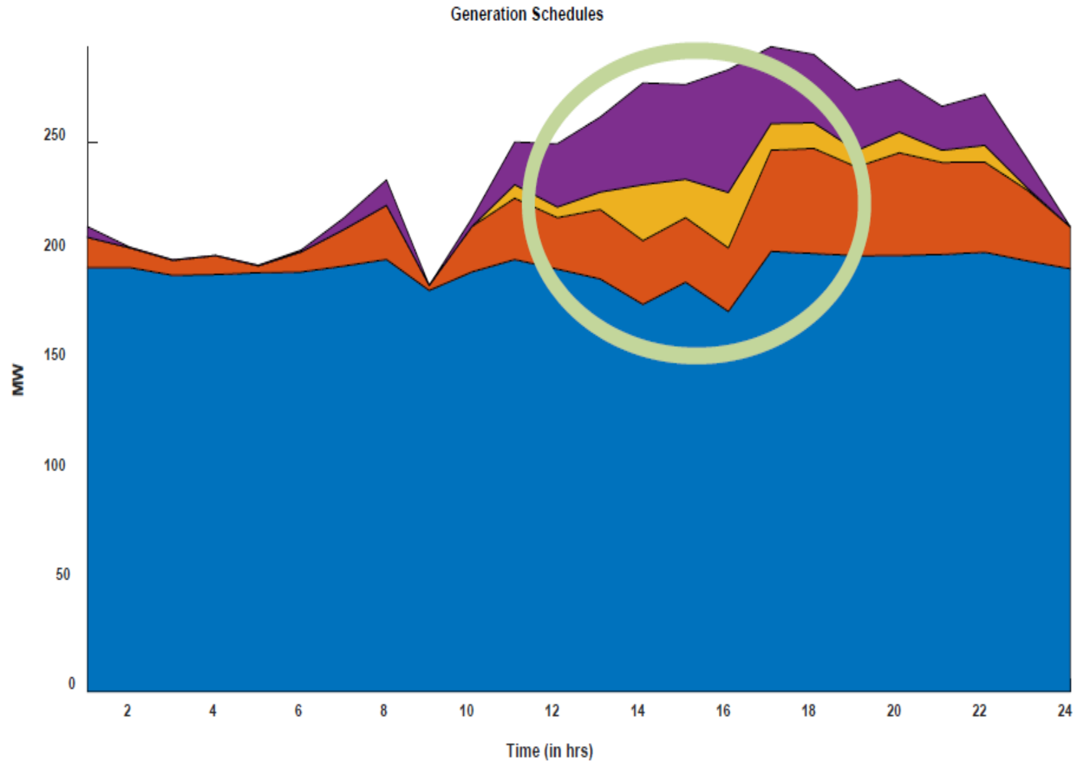




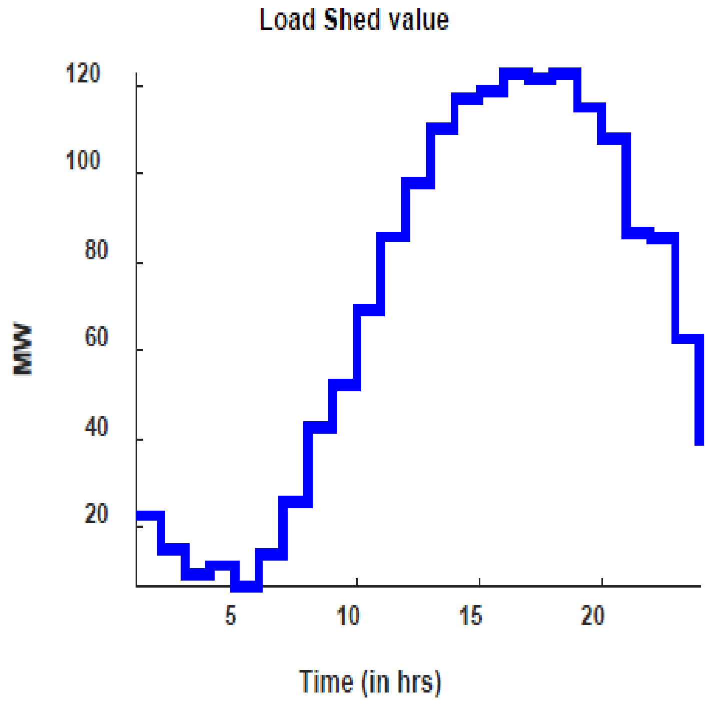


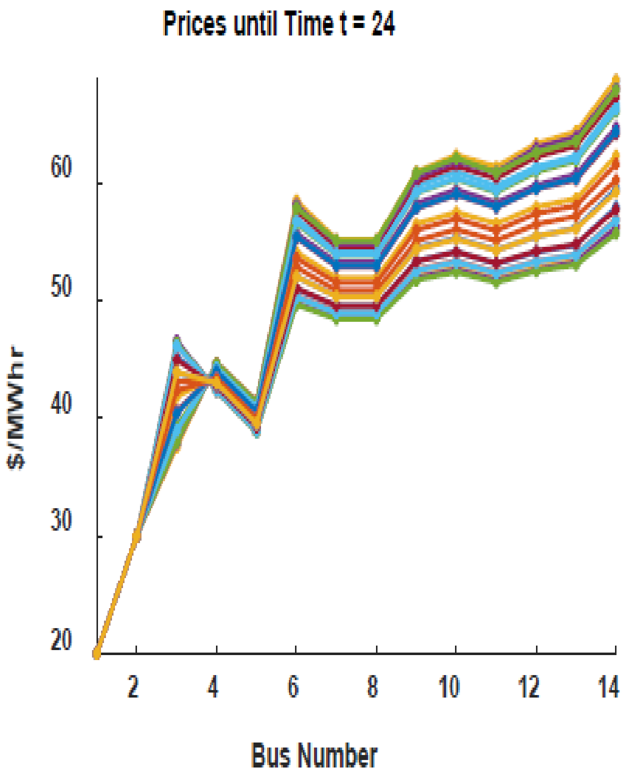
Generation dispatch with/w/o voltage optimization

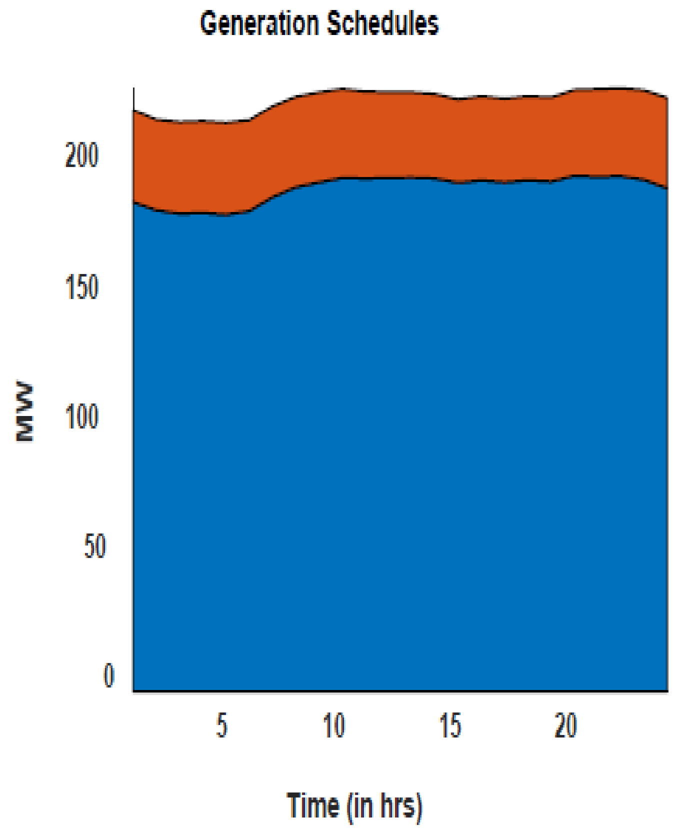




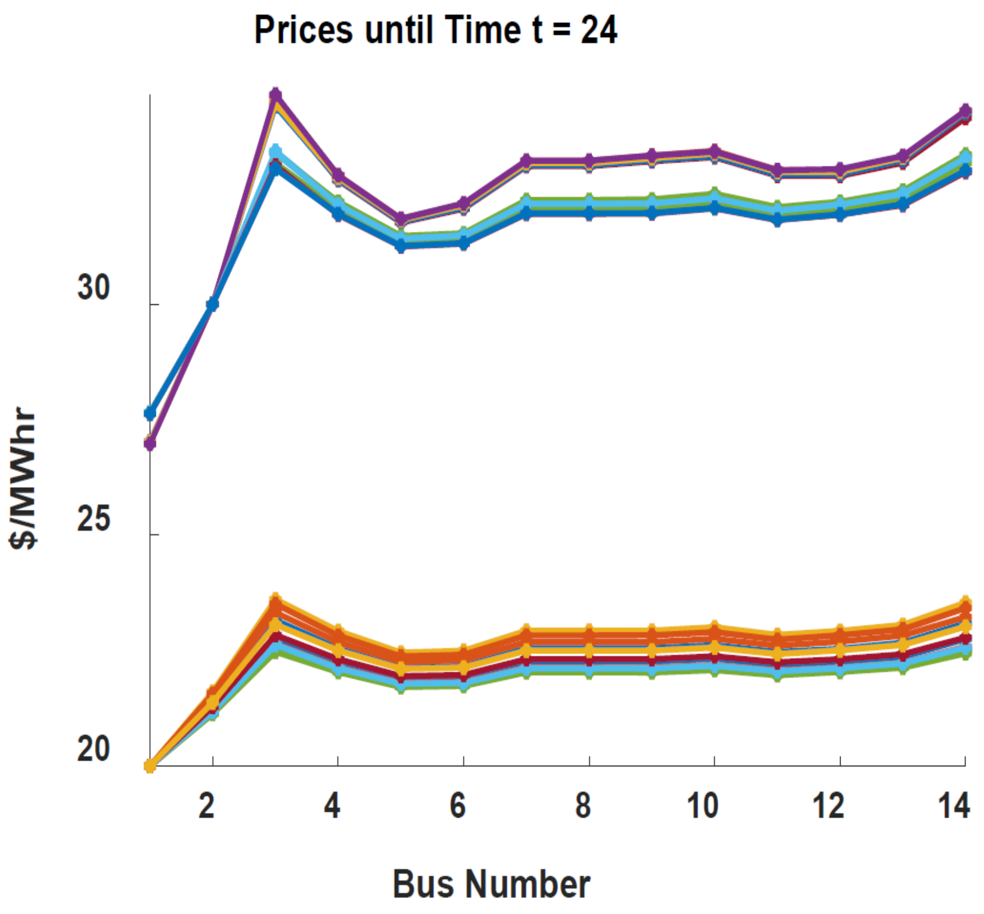
Effect of voltage optimization on load shedding

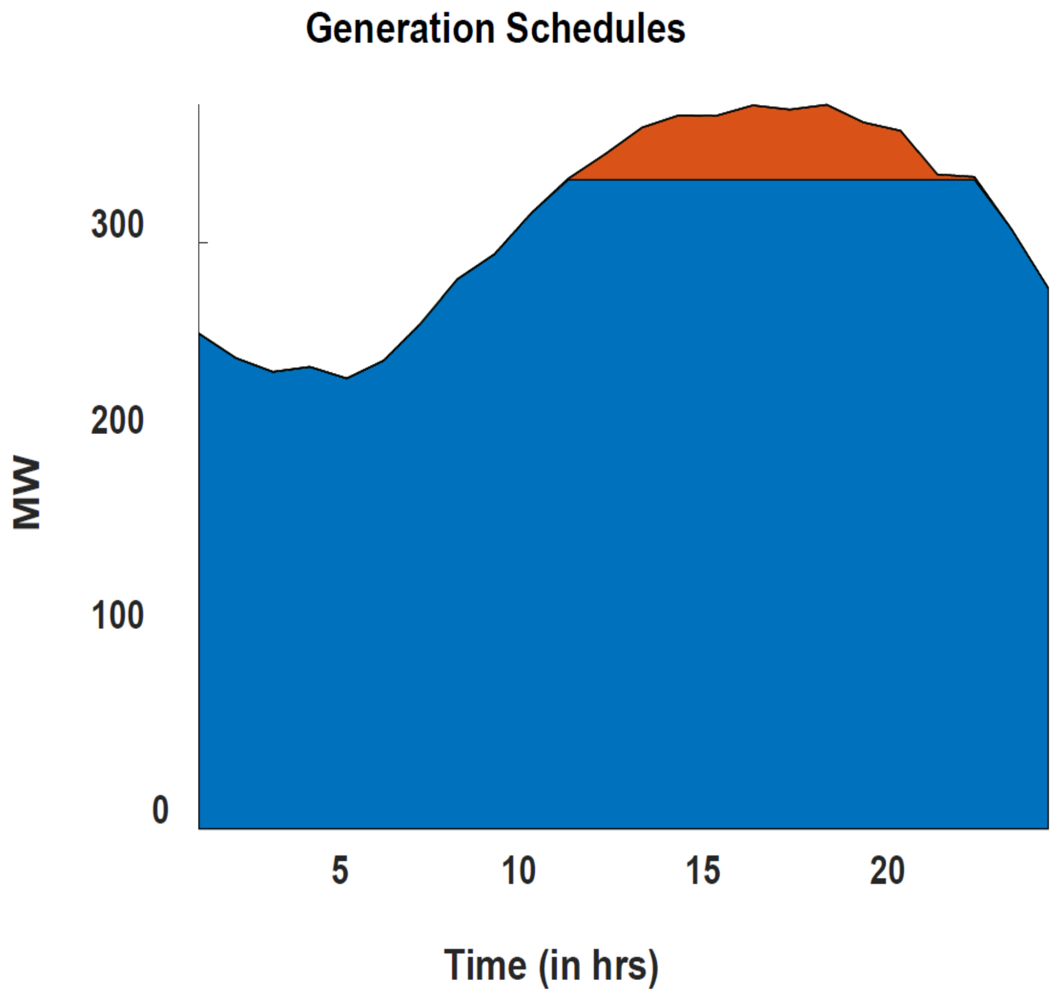




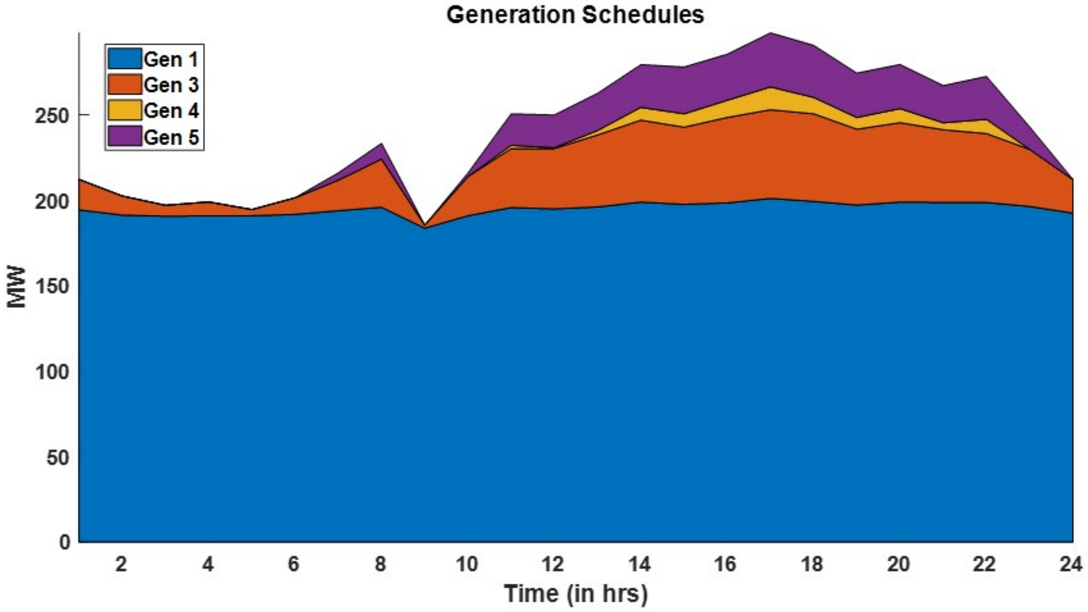


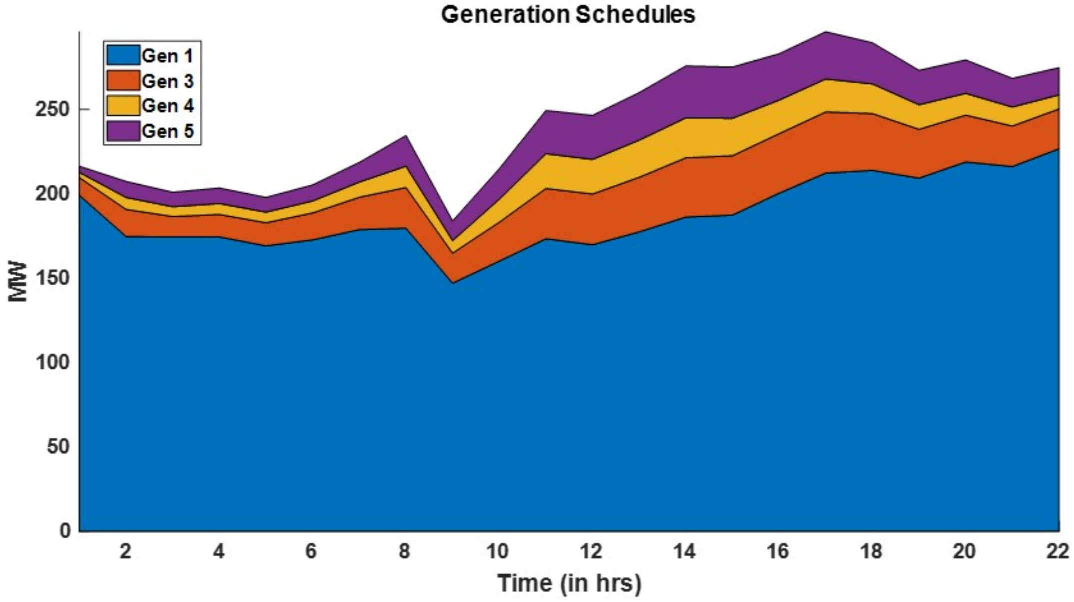
Effect of STATCOM/EV clusters on LMPs and dispatch





Accounting for ramp rates in a look-ahead way





Gen./ DER i	Maximum capacity P_i^{max} (MW)	Linear operations cost coeff. b_i (\$/ MWh)	Quadratic operations cost coeff.a_i (\$/ MWh^2)	Ramp rate MW/HR
1	352	20	0.01	30
3	100	40	0.01	50
6	100	40	0.01	50
8	100	40	0.01	50

Effect of voltage optimization on electricity prices and stakeholders

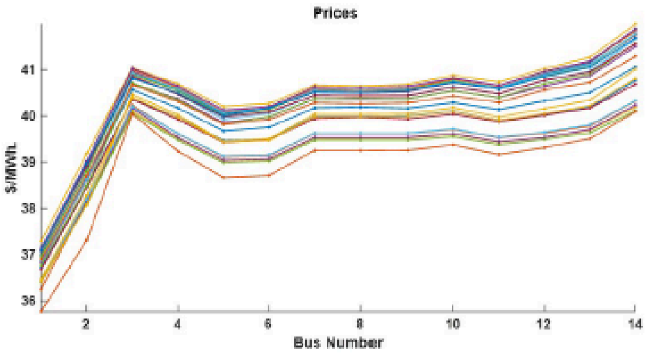


Fig. 18: Cleared prices obtained with voltages optimized in static centralized dispatch: Each line plot corresponds to one timestep

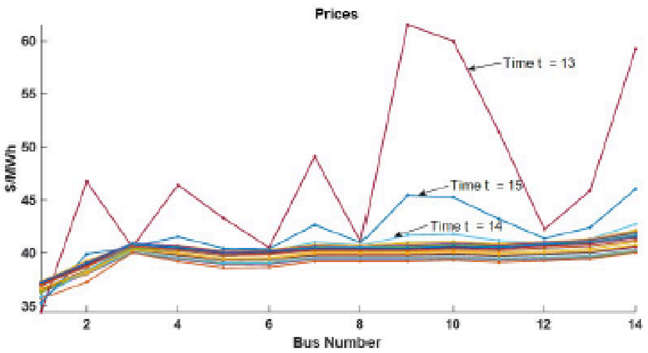
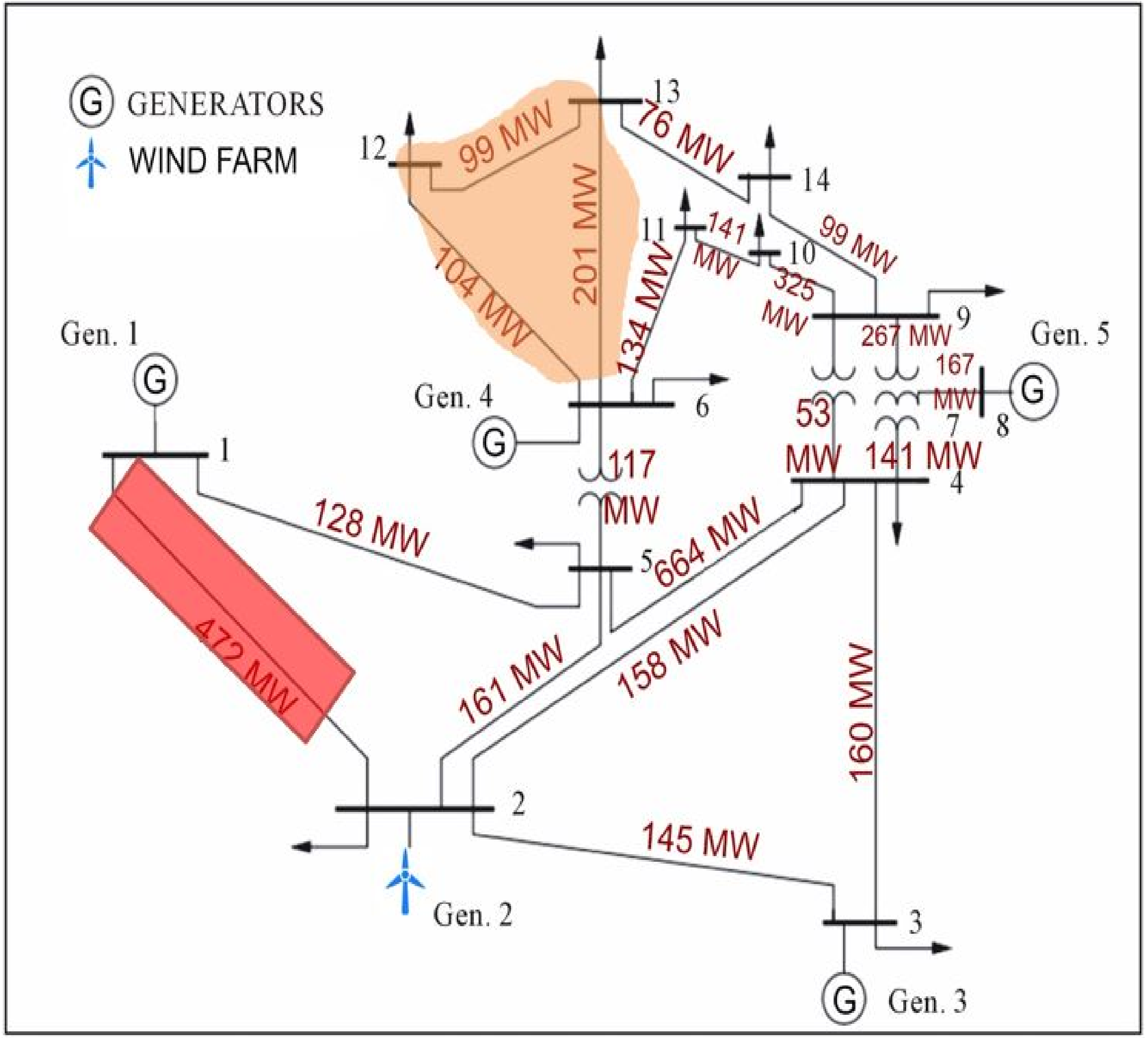
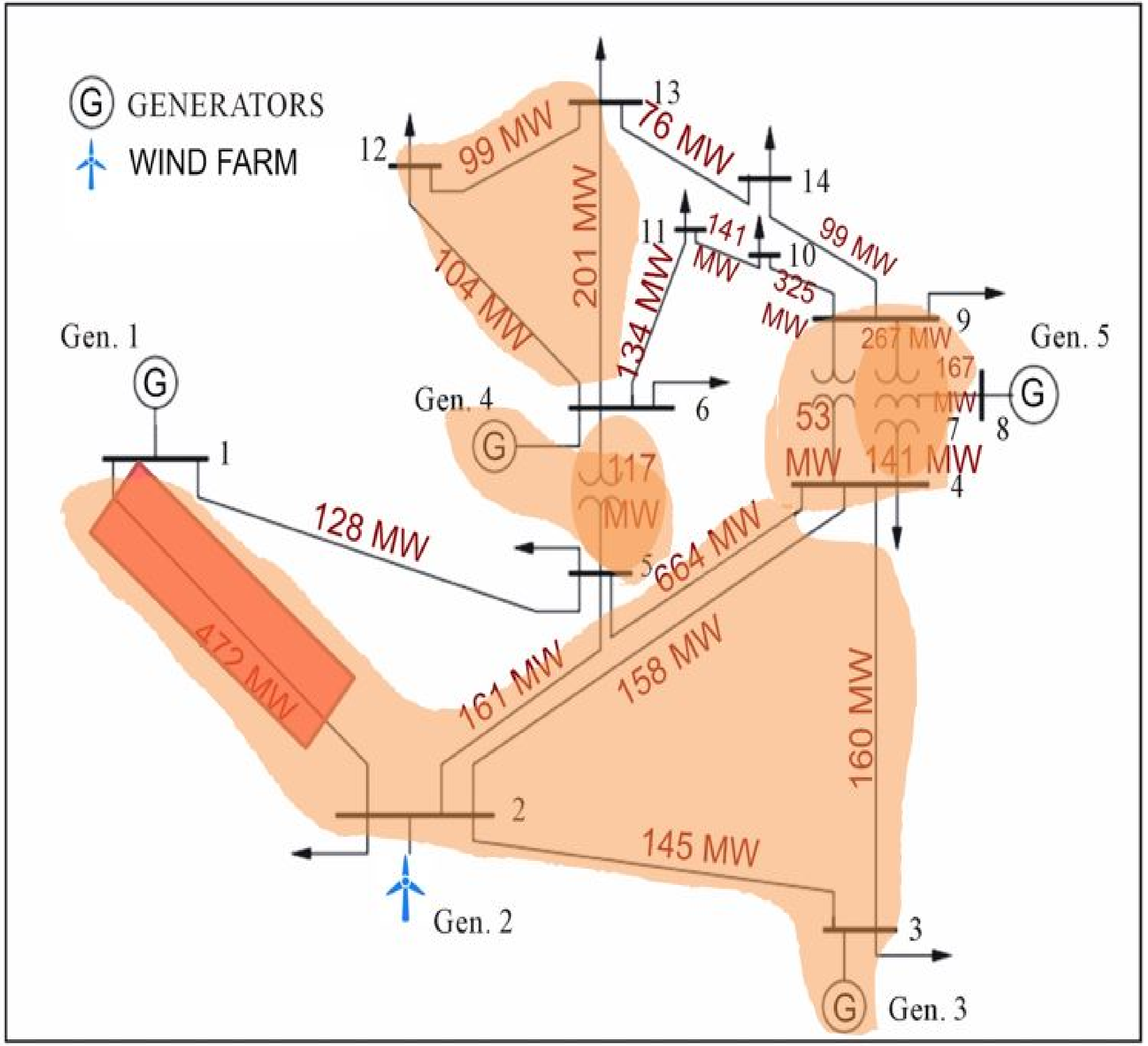


Fig. 19: Cleared prices obtained with voltages optimized in static centralized dispatch: : Each line plot corresponds to one timestep

Metric	Static centralized clearing without voltage dispatch	Static centralized clearing WITH voltage dispatch	MPC-based clearing with voltage dispatch
Load Shed	0.21	0	0
Operating cost	177,850	177,931	184,379
Generator revenues	216,364	217,445	221,682
Generator profit	28,514 (+21.65%)	39,514 (+22.21%)	37,302 (+20.23 %)
Consumer bills	251,882	250,071	230,172
Marginal surplus	35,517	32,625	8489.90

Dependence on contingency screening method





SUMMARY OF RESERVES FOR (N-2) CONTINGENCIES

Time step	Without voltage dispatch			With voltage dispatch		
	Operating reserves	Security reserves	Spinning Reserves	Operating Reserves	Security Reserves	Spinning Reserves
1	Max of 2.63 MW at Bus 3	51.2 MW (Gen 3, Branch 1-2)	204.11 MW (Branch 1-2, Branch 6-11)	Max of 51.9 MW at Bus 8	44.8 MW (Gen 3, Branch 1-2)	204.11 MW (Branch 1-2, Branch 6-11)
7	Max of 2.65 MW at Bus 3	51.13 MW (Gen 3, Branch 1-2)	207.98 MW (Branch 1-2, Branch 6-11)	Max of 35.7 MW at Bus 3	22.06 MW (Branch 1-2, Branch 1-5)	72.84 (Gen 3, Gen 4)
13	Max of 2.67 MW at Bus 8	74.99 MW (Gen 3, Branch 1-2)	252.91 MW (Branch 1-2, Branch 6-11)	Max of 55.94 MW at Bus 6	27.98 MW (Branch 1-2, Branch 1-5)	111.15 (Gen 3, Gen 4)
19	Max of 3.26 MW at Bus 8	78.66 MW (Gen 3, Branch 1-2)	265.12 MW (Branch 1-2, Branch 6-11)	Max of 52.2 MW at Bus 8	29.26 MW (Branch 1-2, Branch 1-5)	114.73 (Gen 3, Gen 4)

Effect of secure voltage dispatch on market outcomes

Metric	Without Voltage Dispatch	With Voltage Dispatch	% change
Load Shed with reserve procurement	0	0	0
Load Shed without reserve procurement	65,918. 50 MWh	98,670.66 MWh	+49.68
Operating cost	$ 136,451.05	$ 135,871.84	- 0.42
Revenues	$ 171,287.31	$ 115,358.95	- 32.65
Generator Profit	$ 34,833.32 (+25.52%)	$ -20,512.89 (-15.10%)	-158.88
Cost of Reserves	$ 360,033.11	$ 189,530.93	**- 47.3%**
Consumer Bills	$ 239,757.28	$ 173,116.58	- 0.72
Marginal Surplus	$ 68,469.97	$ 57,757.63	- 8.14

MAIN OBSERVATIONS--operations

- THE VALUE OF INTERMITTENT RESOURCES AND NON-WIRE SOLUTIONS CRITICALLY DEPENDENT ON HOW OPERATIONS ARE DONE
- Voltage limits and ramp rates most critical.
- Operating battery cost not as critical as SOC constraints.
- Voltage constraints determine when batteries can be scheduled. Cleared prices significantly different with and without voltage management.
- Predictions/decision time horizons important. Data-enabled ML.
- **Market outcomes non-robust w.r.t to how good predictions are.**

Functions comprising today's electricity service	Today software and its limitations	Proposed minimally coordinated distributed operations	Major benefits (inclusion of multiple technologies)
1) Supply-demand balancing (capacity-based; no reliance on flexible non-generation; non-wire solutions)	Static; not co-optimized with 3), 5) and 6); nuclear and hydro power under-utilized	Model predictive control; dynamic dispatch; co-optimization with 3), 5), 6)	Major cost savings; non-volatile (positive LMPs);
2) Delivery losses			
3) Grid ``congestion" (thermal, voltage)	Voltage not co-optimized to support 1), 2), 5), 6)	AC Optimal Power Flow: Compute critical locations, type and amounts	Much larger use of available resources, all else the same
4) Ancillary services (stability, QoS)	Expensive fast generation units (combined cycle), not co-optimized with 3)	Mix of DERs, clusters of EVs. ``Synthetic" reserve	Reduced wear-and-tear; high QoS; use of power electronics
5) Reliability	Analysis; ``worst case" approach; Not optimized reserves, voltage	Optimized preventive reserve; voltage support Data-enabled corrective dispatch	MAJOR CUMMULATIVE SAVINGS; GRADUAL CONTROLLED SERVICE DEGRADATION; NO WIDE-SPREAD BLACKOUTS
6) Resiliency	???? Imminent wide-spread blackouts	Optimized preventive reserve; voltage support; Data-enabled corrective dispatch; reliance on micro-grids and storage	POSSIBLE TO SERVE CRITICAL LOADS; RELIANCE ON STORAGE; DIFFERENTIATED RELIABILITY OF SERVICE

Recommendations and next steps

- System operator/market needs an advisory tool regarding flexible utilization of resources. No longer proxy limits!
- Distributed MPC at the bidding stage extremely useful and overcomes huge SCUC computational problems when seeking deliverable power solutions. Implementable bid functions.
- AC OPF can be used to identify candidate non-transmission solutions (clusters of EVs; STATCOMs; synchronous condensers)
- Deliverable reliability reserves that work!

Next steps

- **Continuing challenge (FERC Conf 2021) –can we do better than DyMoNDS? (interested in following up between now and then…)**
- **Remaining research problem: Creating robust bid physically implementable bid functions**
- Simulations of physically implementable bid functions available at request

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THANK YOU