Initial Studies on Integrating Demand Response Aggregators and Carbon Taxation into Electricity Markets

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INTRODUCTION

- **Motivation: Environment**
  - Electric industry is the major source of GHG emissions in the US
  - Proactive efforts needed to alleviate alarming consequences of climate change
  - Carbon tax is a promising solution
    - It led to 93% drop in coal-fired generation in the UK
- **Motivation: Demand response**
  - U.S. Smart Grid Initiative calls for integration of demand response (DR) and demand side resources
  - Developments in advanced metering infrastructure (AMI) and bidirectional communication enable implementing DR programs
- **Contributions**
  - Simulating multiple DR aggregators based on the Smart Grid Resource Allocation (SGRA) approach in a two-area power system and study nodal prices, peak demand reduction, and carbon emissions reduction
  - Adapting a carbon tax function for fossil-fueled generators aligned with a temperature increase limit of 2℃
  - Studying effects on GHG emissions
- **SGRA approach**
  - Residential customers allow an ***aggregator*** to reschedule their appliances
    - Aggregator is a for-profit market entity between the bulk power market and customers
    - Residential customers can lower electricity price offered by the aggregator

PROBLEM STATEMENT

- **Carbon tax, $T(E)$**
  - For fossil-fueled generators based on emission rates, E, in (CO_2/MWh)

$$T(E) = 30\,E$$

- **CO_2 emission reduction of generator in a day**

$$E_{reduced} = \sum_{h=0}^{24} \left[\left(G_h^{untaxed} - G_h^{taxed} \right) \times E \right]$$

  - $E_{reduced}$: CO_2 emissions reduced in a 24-hour period in metric tons
  - $G_h^{untaxed}$: energy produced by a generator in hour h before taxation in (MWh)
  - G_h^{taxed}: energy produced by a generator in hour h after taxation in (MWh)

- **Tax revenue collected from a power plant**

$$R_{tax} = \sum_{h=0}^{24} \left[G_h^{taxed} \times T(E) \right]$$

  - R_{tax} : tax revenue collected from a fossil-fueled generator in ($)

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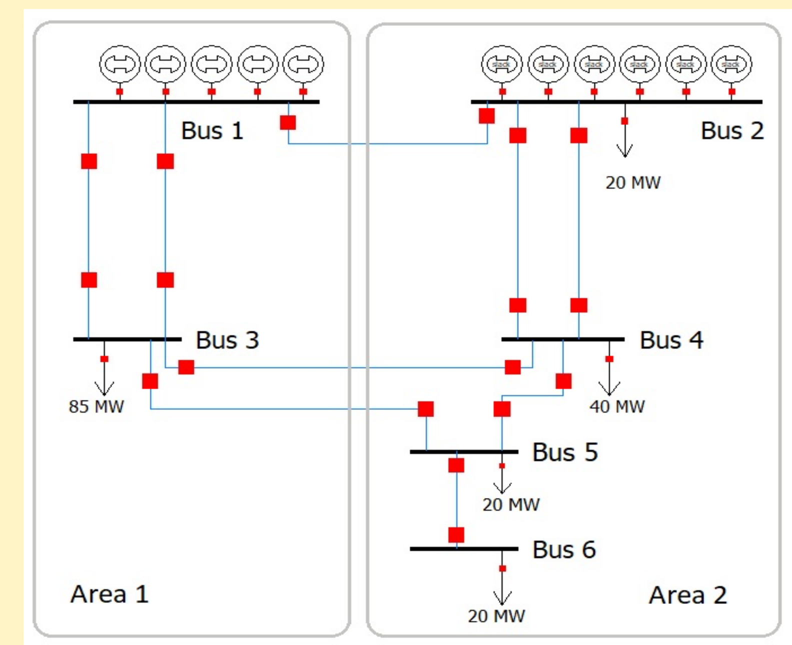
SYSTEM MODEL

- **Roy Billinton Test System (RBTS)**
  - Six buses and nine transmission lines
  - 11 generators with 240 MW installed capacity
  - Nominal load of 185 MW
  - Divided into two areas connected by three lines
  - Two 5 MW generators are classified as peak units
  - Modified by moving a 5 MW generator from bus 2 to bus 1

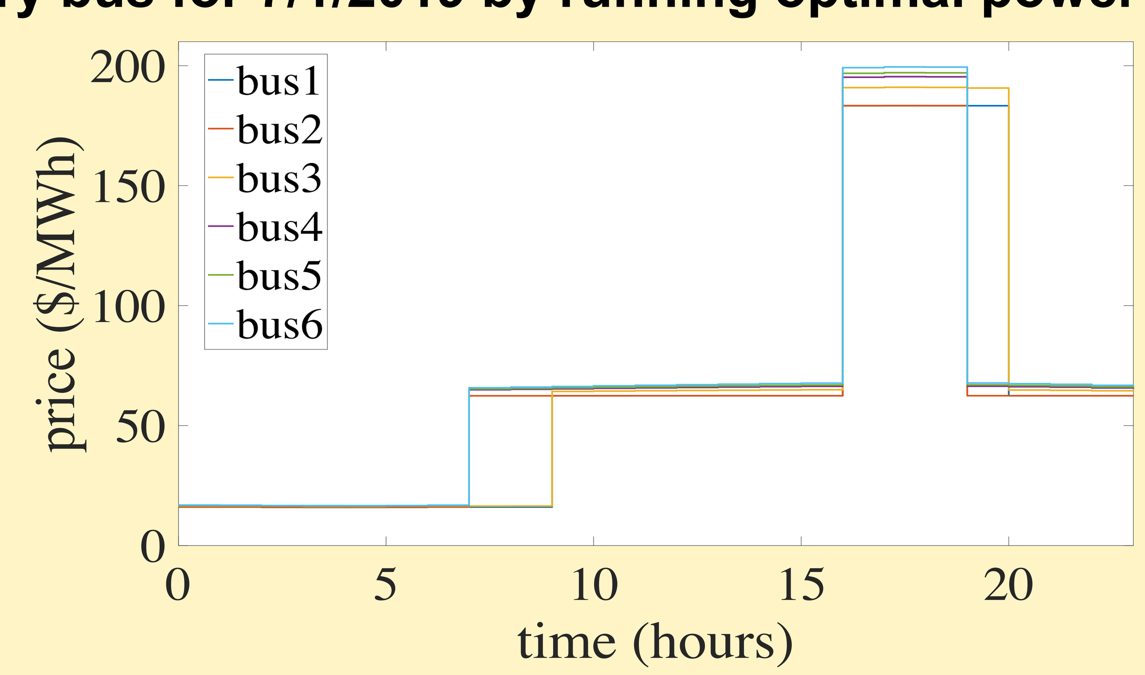


- **Generation data**
  - P_i: real power output of generator i in MW
  - C_i: total cost function of generator i in $

Area no.	Generator no.	Classification	Fuel type	Capacity (MW)	Marginal cost function ($/MWh)
1	1	base load	coal	40	$\frac{dC_1(P_1)}{dP_1} = 0.0146P_1 + 15.52$
	2	base load	nuclear	40	$\frac{dC_2(P_2)}{dP_2} = 0.0146P_2 + 15.52$
	3	intermediate	hydro	20	$\frac{dC_3(P_3)}{dP_3} = 0.0026P_3 + 62.41$
	4	intermediate	natural gas	10	$\frac{dC_4(P_4)}{dP_4} = 0.0026P_4 + 62.41$
	5	peak	natural gas	5	$\frac{dC_5(P_5)}{dP_5} = 0.0064P_5 + 183.32$
2	6	base load	nuclear	40	$\frac{dC_6(P_6)}{dP_6} = 0.0146P_6 + 15.52$
	7	base load	coal	20	$\frac{dC_7(P_7)}{dP_7} = 0.0146P_7 + 15.52$
	8	base load	coal	20	$\frac{dC_8(P_8)}{dP_8} = 0.0146P_8 + 15.52$
	9	intermediate	hydro	20	$\frac{dC_9(P_9)}{dP_9} = 0.0026P_9 + 62.41$
	10	intermediate	natural gas	20	$\frac{dC_{10}(P_{10})}{dP_{10}} = 0.0026P_{10} + 62.41$
	11	peak	natural gas	5	$\frac{dC_{11}(P_{11})}{dP_{11}} = 0.0064P_{11} + 183.32$

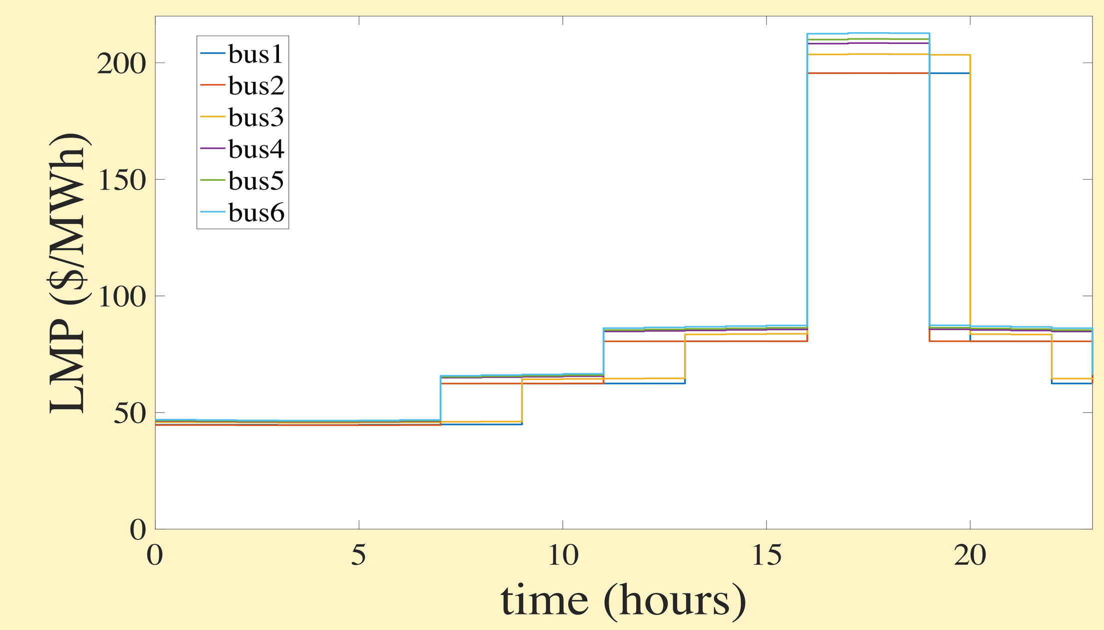
- **Load data**
  - Real load data from PJM on 7/1/2019
  - Scaled to fit nominal load values at load buses of RBTS

- **Locational marginal price (LMP) or nodal price found at every bus for 7/1/2019 by running optimal power flow (OPF)**

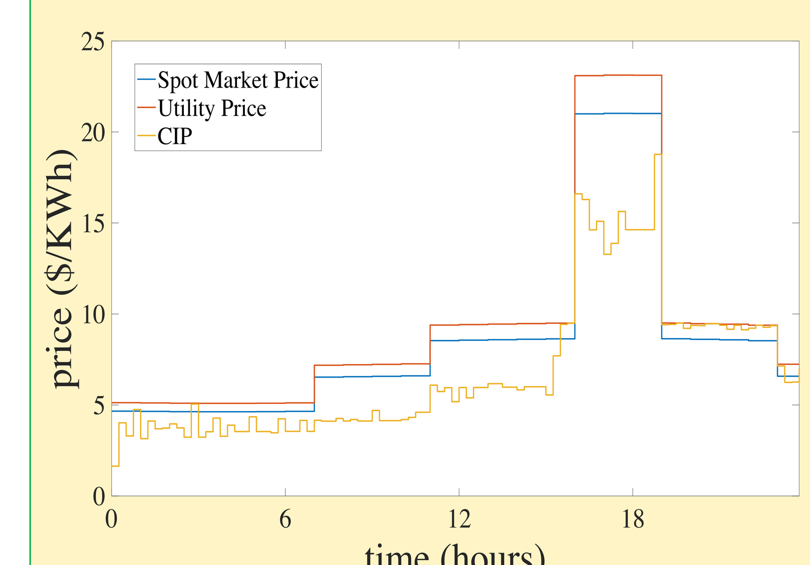


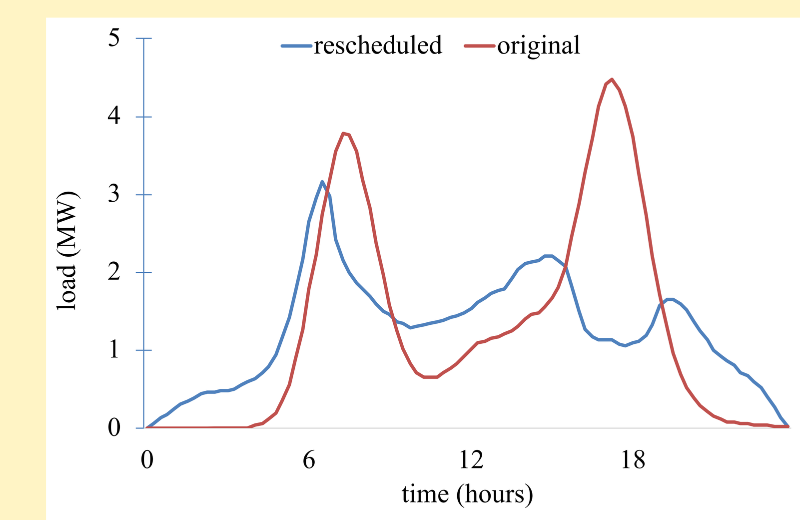
RESULTS

- **Effect of carbon tax on nodal prices**
  - LMPs have increased after taxing fossil-fueled generators



- **Aggregators at buses 2-6 achieve peak demand reductions by rescheduling controllable assets through SGRA**





- **Generation output and CO_2 reduction**

Area	Gen. type	Daily generation w/o tax (MWh)	Daily generation with tax (MWh)	Δ generation (MWh)	CO_2 reduced (metric ton)	Daily tax revenue ($)
1	coal	854	907	53	50.93	24,620
	natural gas	64	122	58	35.03	1,160
2	coal	900	960	60	57.66	25,947
	natural gas	158	222	64	38.66	2,862

CONCLUSION

- SGRA approach offers many benefits to interconnected electricity grids for
  - displacing dirty peaking units from peak times
  - providing competitive market-based pricing
- Carbon taxation for fossil-fuel generation promises to
  - reduce GHG emissions of base-load and peaking units
  - supporting investment of cleaner generation