Wind power integration and consumer behavior: a complementarity approach

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Background

❑ Motivation for demand response

- Enhancing competition
- Improving operational flexibility and reliability of the grid
- Integrating large quantities of variable energy resources

Motivation

- **There can be market power for a large consumer**
  - **Comparatively large number of loads**
  - **Loads distributed throughout the network**
  - **Supply its demand in Day-ahead and Balancing (energy imbalance) markets**
  - **Flexible enough that does not need to be fully supplied**

Aim

- **Explore the extent to which an elastic large consumer exercises its market power and investigate its impacts on:**
  - **Utility of the large consumer**
  - **Locational Marginal Prices (LMPs)**
  - **Dispatch of wind power production**

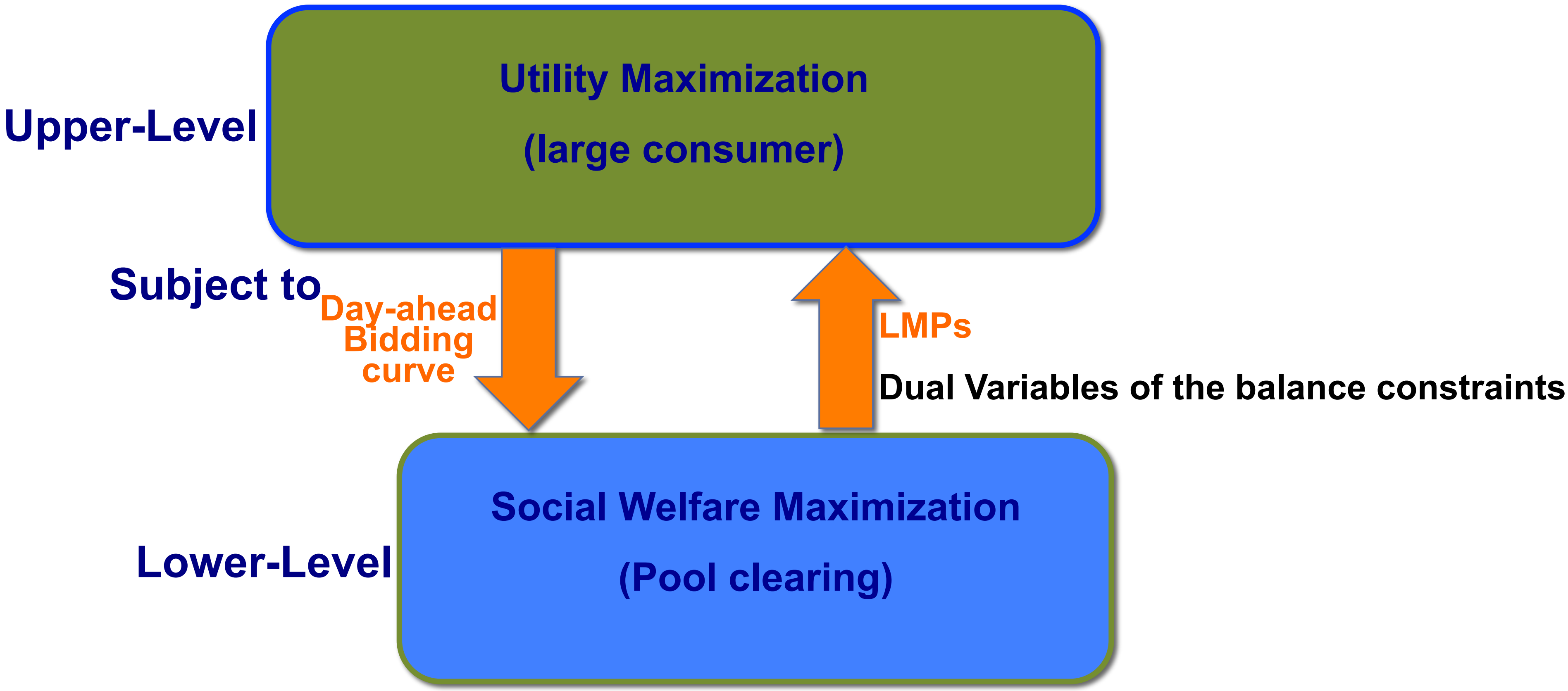
Method

- **A stochastic complementarity model is developed to**
  - **Design the optimal bidding strategy of a strategic large consumer in a wind-integrated pool**
    - **Endogenous formation of LMPs**
    - **Wind power production uncertainty**
  - **Explore the market outcomes of the strategic behavior in different situations**
    - **Case 1: The consumer is allowed to trade in the BM**
    - **Case 2: The consumer is not allowed to trade in the BM**
    - **Case3: The consumer is allowed to trade in the BM but its share of balancing energy provision is lower than that in Case 1**

Approach

❑ Bilevel Model

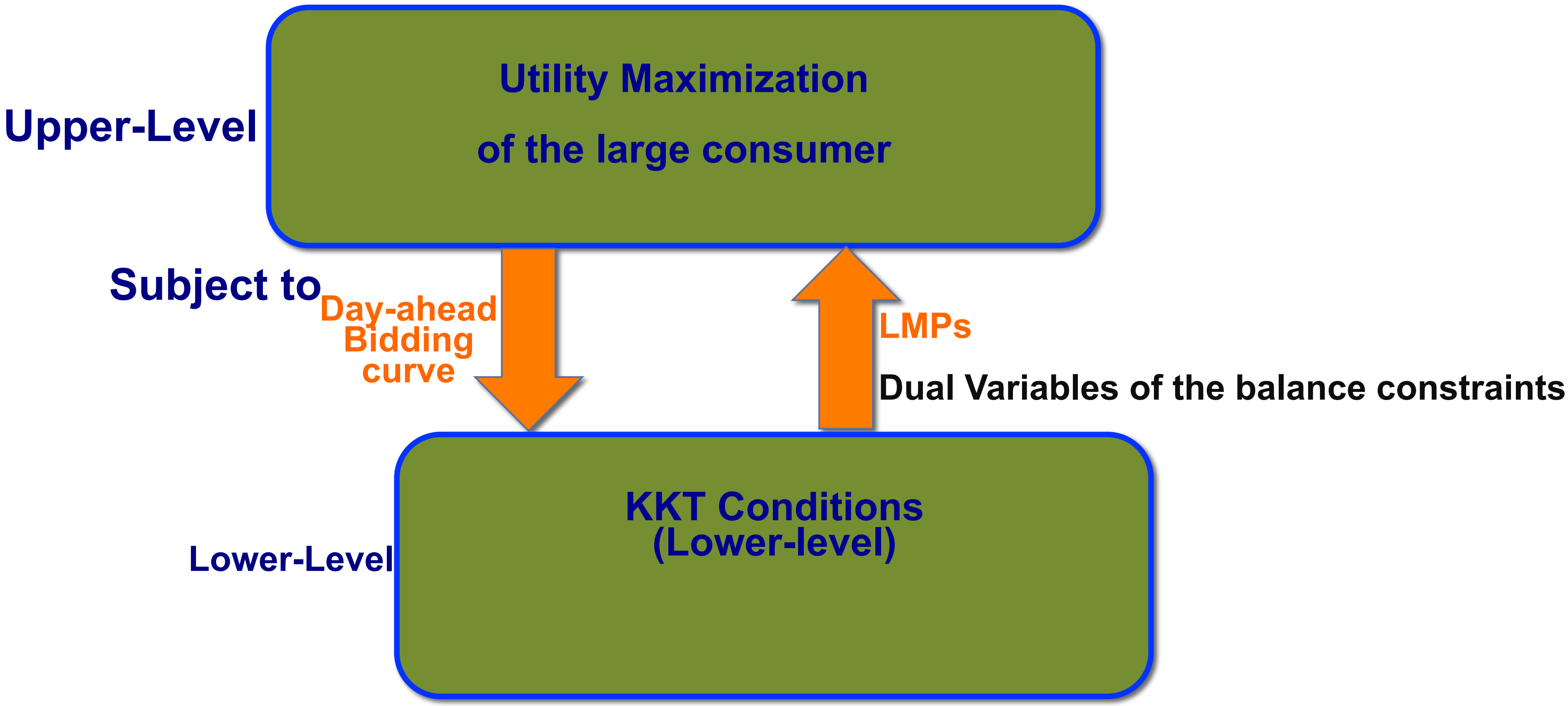
- Optimization problem constrained by other optimization problem (OPcOP)



Approach

❑ MPEC

- ➢ **The OPcOP is recast as an MPEC for the joint solution of both problems**



Approach

❑ Pool clearing model

- The lower-level problem clears a pool with wind producers
- The considered pool is cleared one-day prior to power delivery and on an hourly basis
- The pool-clearing algorithm is a single-period network constrained auction
- The pricing scheme of the model is proved to guarantee the revenue adequacy of the market and generation cost recovery of the producers
- The pool clearing is cast as a two-stage stochastic programming model to take into account wind power production uncertainty
- Day-ahead market decisions are made accounting for different operating conditions in the balancing market

Approach

- Scenario tree of the pool-clearing model

First Stage (DAM)

Second Stage (BM Prognosis)

Scenario-independent decisions

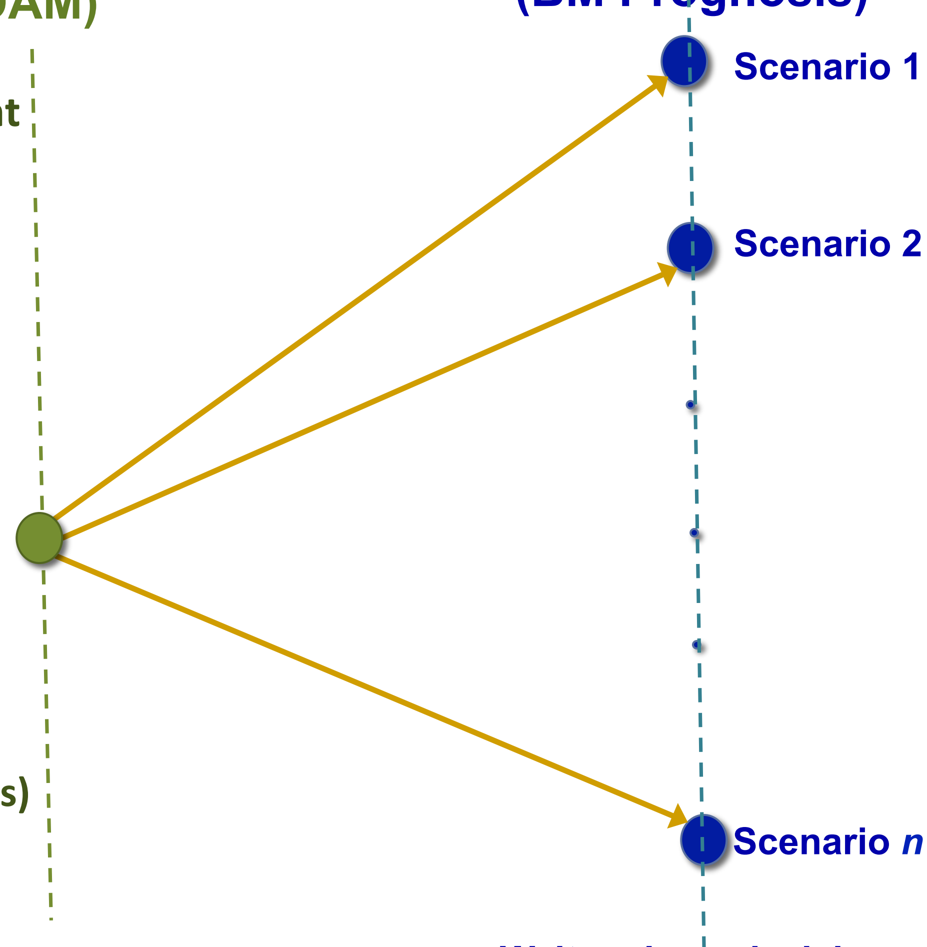
(Primal Variables)

1- Scheduled energy production and consumption in the DAM

2- Scheduled wind production

(Dual Variables)

Day-ahead prices (LMPs)



Here and now decisions

Wait and see decisions

Scenario-dependent decisions

(Primal Variables)

1- Deployment of balancing energy

2- Involuntary load shedding

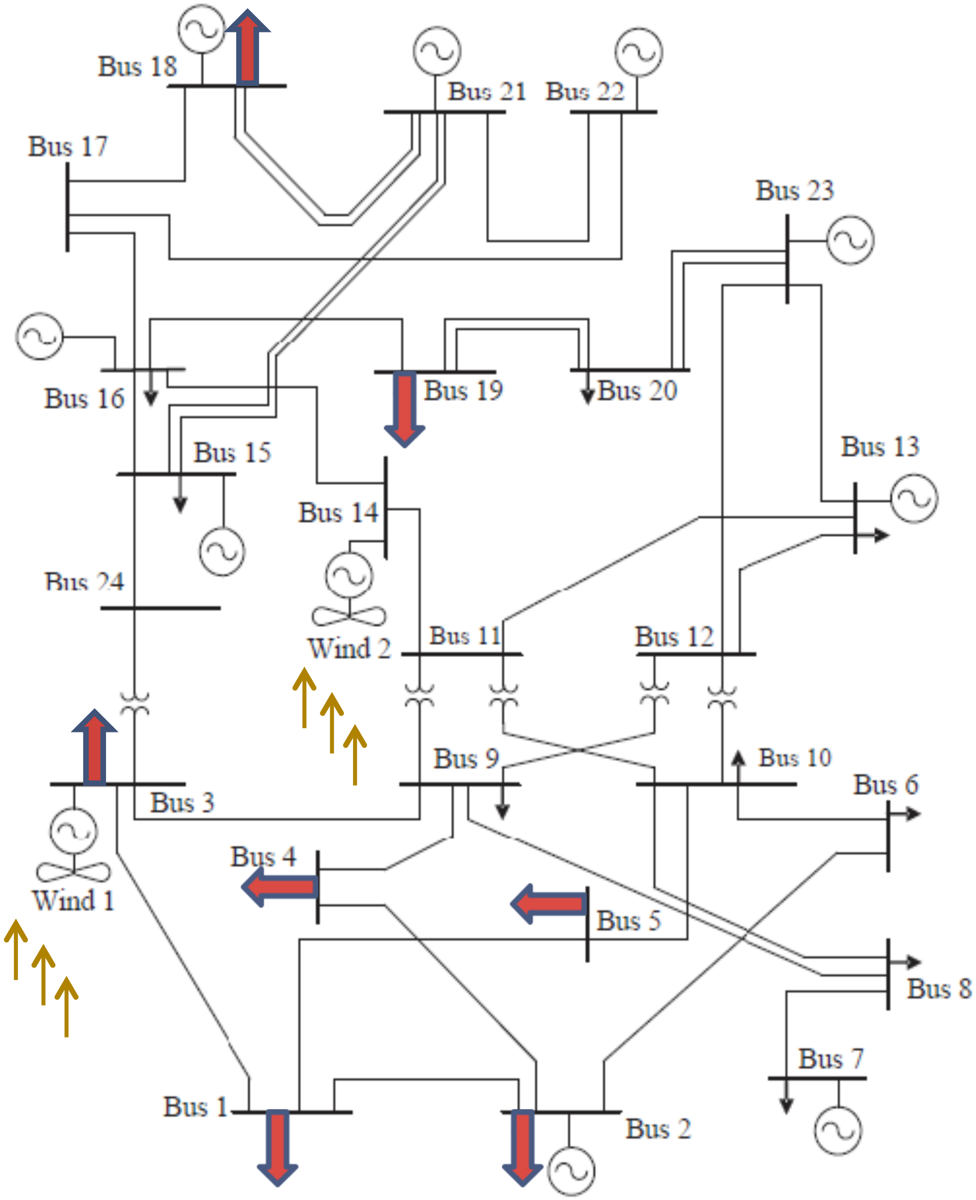
3-Wind power spillage

(Dual Variables)

4-Balancing prices (LMPs)

Results

- IEEE 24-node RTS for a single hour as the illustrative case study
- 32 units, 17 loads and 2 wind farms
- The strategic large consumer own 7 loads in different locations
- Max consumption of the consumer is 1065 MW , 37% of the total maximum consumption (2907 MW)
- Two wind farms in different location
- 30 wind power production scenarios
- VOLL is assumed to be $10000/MWh



Results

- **Case 1: Demand side is allowed to trade in the BM**
- **In all cases, transmission constraints are non-binding**

Case 1: Consumer is allowed to participate in the BM		
	Strategic	Competitive
Energy bid price ($/MWh)	13.58	Marginal utility
Scheduled demand in the DAM (MWh)	953	999
LMP ($/MWh)	13.58	15.00
Expected energy not supplied (MWh)	47.0	0.0
Expected Utility ($)	9517	8249

Results

- **The large consumer underbids its expected demand in the DAM instead of bidding the marginal utility of its loads which are higher**

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Results

- **Large consumer underbids its expected demand in the DAM instead of bidding the marginal utility of its loads**
- **Lower consumption is scheduled in the DAM for the large consumer relative to the competitive bidding**

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Results

- **Strategic consumer underbids its expected demand in the DAM instead of bidding the marginal utility of its loads**
- **Lower consumption is scheduled in the DAM for the strategic consumer relative to the competitive bidding**
- **Day-ahead LMPs are lower with strategic bidding**

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- **Day-ahead LMPs are lower with strategic bidding**
- **Unlike competitive bidding, the consumer's demand is not fully supplied in the BM with strategic bidding**

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- Unlike competitive bidding, the consumer's demand is not fully supplied in the BM with strategic bidding (%4.5 of its consumption is not supplied)

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Results

- Strategic consumer underbids its expected demand in the DAM instead of bidding the marginal utility of its loads
- Lower consumption is scheduled in the DAM for the strategic consumer relative to the competitive bidding
- Day-ahead LMPs are lower with strategic bidding
- Unlike competitive bidding, the consumer's demand is not fully supplied in the BM with strategic bidding (%4.5 of its consumption is not supplied)
- Expected Utility of the large consumer increases significantly (%15.37 in this case)

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Results

- **Impacts on dispatch of wind production & balancing market operation**

Case 1: Consumer is allowed to participate in the BM		
	Strategic	Competitive
Scheduled Consumption the DAM (MWh)	953	999
Scheduled wind in the DAM (MWh)	101.7	121.7
Expected utility in the BM ($/MWh)	501.3	407.8

Results

- **Impacts on dispatch of wind production & balancing market operation**

  - **Due to the strategic bidding, Lower consumption is scheduled in the DAM**

Case 1: Consumer is allowed to participate in the BM		
	Strategic	Competitive
Scheduled demand in the DAM (MWh)	**953**	**999**
Scheduled wind in the DAM (MWh)	101.7	121.7
Expected utility in the BM ($/MWh)	501.3	407.8

Results

❑ Impacts on dispatch of wind production & balancing market operation

- **Due to the strategic bidding, Lower consumption is scheduled in the DAM relative to the competitive case**
- **Less wind production is scheduled in the DAM**
- **The amount of wind energy in the BM scenarios and the required downward balancing energy increase**

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Results

❑ **Impacts on dispatch of wind production & balancing market operation**

- **Due to the strategic bidding, Lower consumption is scheduled in the DAM relative to the competitive case**
- **Less wind production is scheduled in the DAM**
- **The amount of wind energy in the BM scenarios and the required downward balancing energy increases**
- **Providing downward balancing energy means more consumption for consumers**
- **The expected utility of the consumer in the BM is %20 higher with strategic bidding**

Case 1: Consumer is allowed to participate in the BM		
	Strategic	Competitive
Scheduled demand in the DAM (MWh)	953	999
Scheduled wind in the DAM (MWh)	101.7	121.7
Expected utility in the BM ($/MWh)	**501.3**	**407.8**

Results

- **Benefits of participation of the consumer in the balancing market**
  - **Case 1: Demand side is allowed to trade in the BM**
  - **Case 2: Demand side is not allowed to trade in the BM**

Case 1: Consumer is allowed to participate in the BM		
	Case 1	**Case 2**
Expected energy not supplied (MWh)	47	112
Total Expected utility ($)	9517	9119

Results

- **Impact of participation of large consumer in the balancing market on its strategic behavior**
  - **Case 1: Demand side is allowed to trade in the BM**
  - **Case 2: Demand side is not allowed to trade in the BM**
  - **Participation in the BM increase the expected utility of the large consumer while reduces its expected energy not supplied**

Outcomes of the strategic behavior in Case 1 & Case 2		
	Case 1	**Case 2**
Expected energy not supplied (MWh)	**47**	112
Total Expected utility ($)	**9517**	9119

Results

- **Impact of large consumer's share in balancing energy provision on its strategic behavior**
  - **Case 3: Large consumer's share of the balancing energy provision is 20%**
  - **Case 4: Large consumer's share of the balancing energy provision is 16**

Outcomes of the strategic behavior in Case 3 & Case 4		
	Case 3	**Case 4**
Expected energy not supplied (MWh)	47	54
Total Expected utility ($)	9517	9477

Results

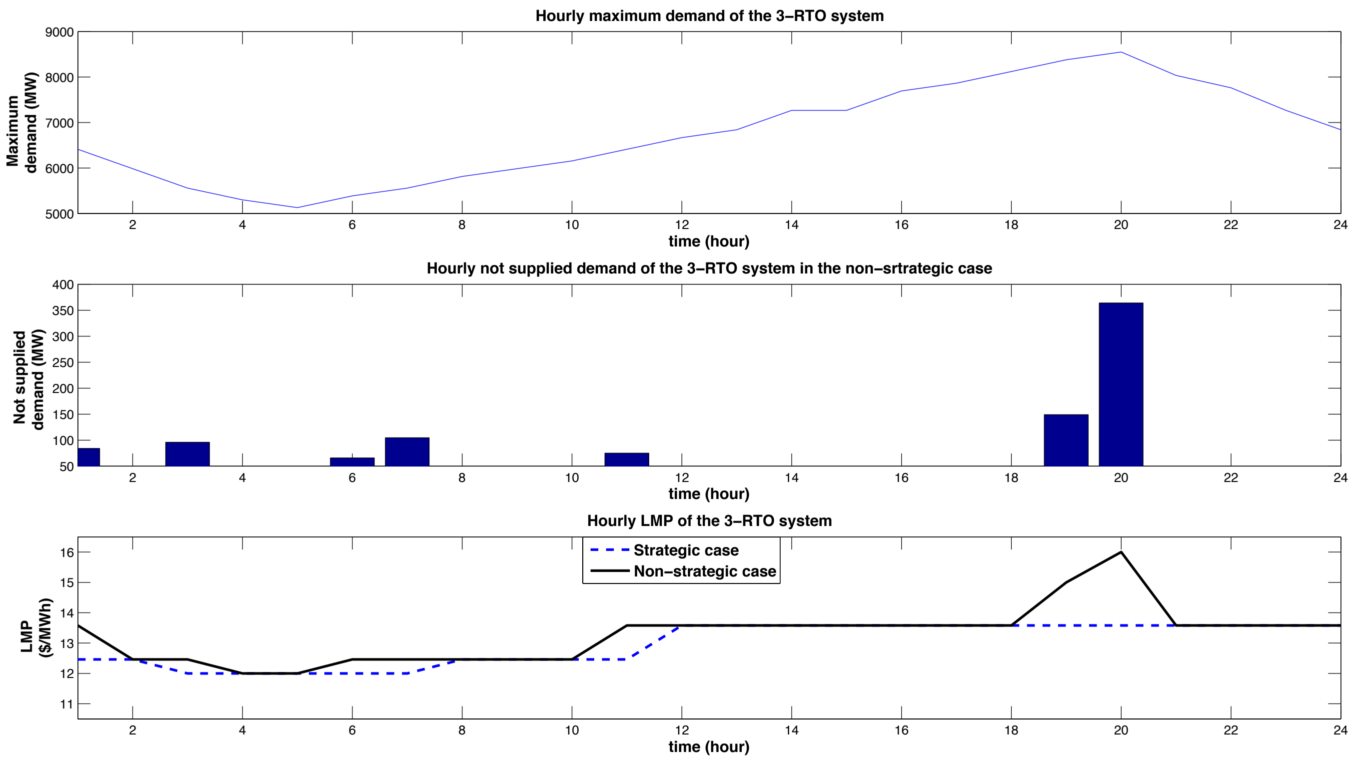
- **Impact of large consumer's share in balancing energy provision on its strategic behavior**
  - **Case 3: Large consumer's share of the balancing energy provision is 20%**
  - **Case 4: Large consumer's share of the balancing energy provision is 16**
  - **The higher the large consumer's share in providing balancing energy , the lower its expected energy not supplied and the higher its total expected utility**

Outcomes of the strategic behavior in Case 3 & Case 4		
	Case 3	**Case 4**
Expected energy not supplied (MWh)	47	54
Total Expected utility ($)	9517	9477

Results

❑ Large-scale case study

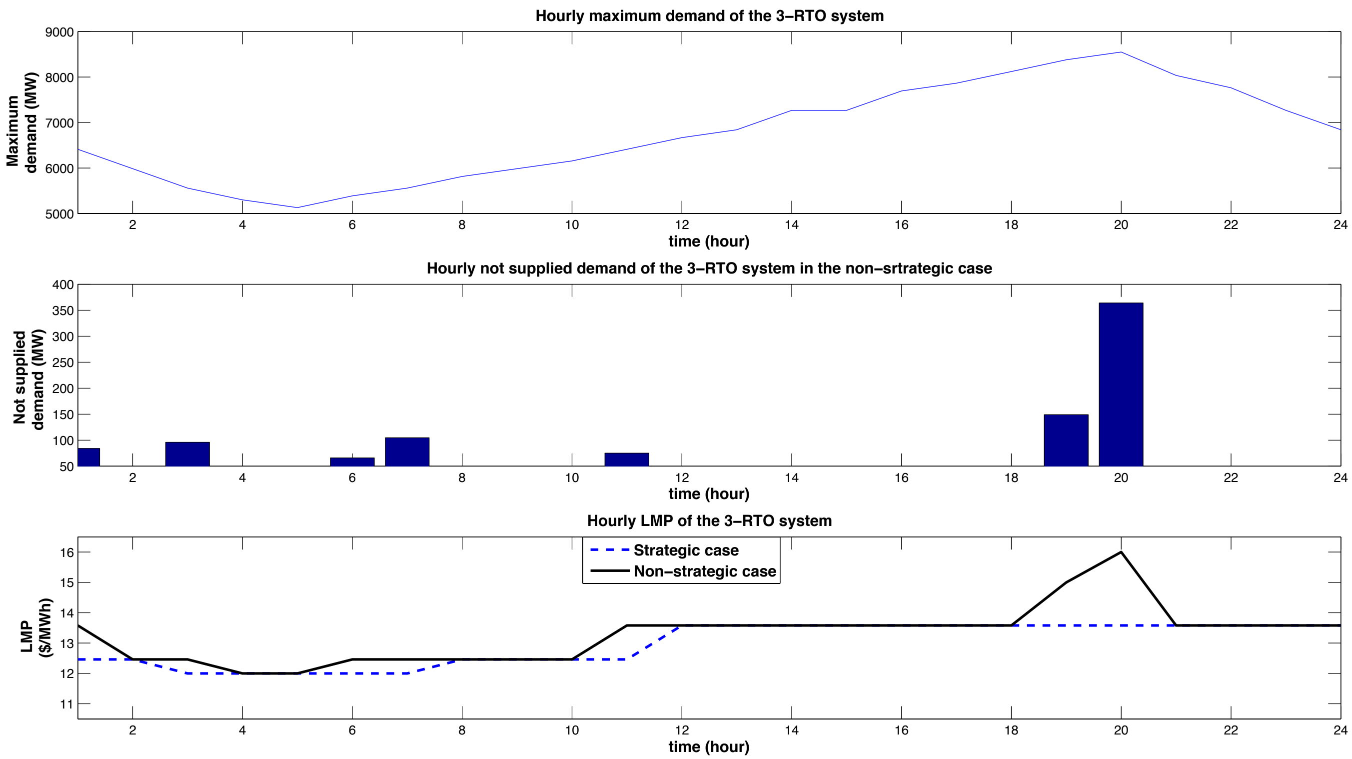
- Model is examined on 3-area IEEE RTS for 24 hours
- Data of Units and consumers is similar to the 1-area RTS
- Three wind farms (one wind farm in each area)



Results

❑ Large-scale case study

- ➢ **The large consumer manipulates the market in 6 hours out of 24 hours in peak and off-peak hours**
- ➢ **The most profitable situation for the large consumer occurs at the peak time**



Conclusions

- Enhanced elasticity may create market power for the a large consumer to manipulate the market outcomes to its own benefit
- A large consumer can underbid its demand in the day-ahead market to alter day-ahead LMPs and maximize its own profits
- However, a small fraction of its demand is not supplied
- Strategic behavior of the large consumer impacts the scheduling of wind power production and may reduce the scheduled wind power production in the day-ahead market
- Participation in the BM increases the large consumer's expected utility when behaves strategically
- As the large consumer's share in balancing energy provision increases, its expected utility increases

Questions?