Energy Management in Microgrids using Demand Response and Distributed Storage –A Multi-Agent Approach

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Contents

- Smart Distribution Systems
- Multi Agent Systems
- Agent based energy trading
- Incorporating DR and DS in smart microgrids
- Case study
- Conclusion

Smart Distribution System

- One of the vital pillars of the smart grid technology
- Acts as a medium of power and data exchange between customers and utilities.
  - Market prices, customer willingness to participate in DR, network operator commands etc.
- May contain large number of DERs integrated through controllable platforms called microgrids.

Smart Microgrid

- A microgrid with ability to support energy management and intelligence to behave in consistence with the smart distribution systems
- Platform to integrate DERs on the community level
- Allows customer participation in the electricity enterprise
- An indivisible module that can be integrated into utility smart grids with less or no modifications in installed intelligence

Multi-Agent Systems

- A system with two or more agents or intelligent agents or even combination of both
- An agent is “a software or hardware entity that is placed in some environment and is able to autonomously react to the changes in that environment
- Greater scalability over quadratic programming and linear programming approaches
- Best suit for developing real-time decision making systems which are robust, flexible and extensible.
- IEEE-PES Multi Agent Systems Working Group

Objective of the work

- *To develop an agent based real-time energy trading cum management framework in consistent with utility smart grids*
  - *Allow DGs with smaller capacities connected in micrograids to trade with local customers*
  - *Inherent diversities in load consumption patterns*
  - *Storage Options*
  - *Encourage and fairly treat customers' participation in DR*

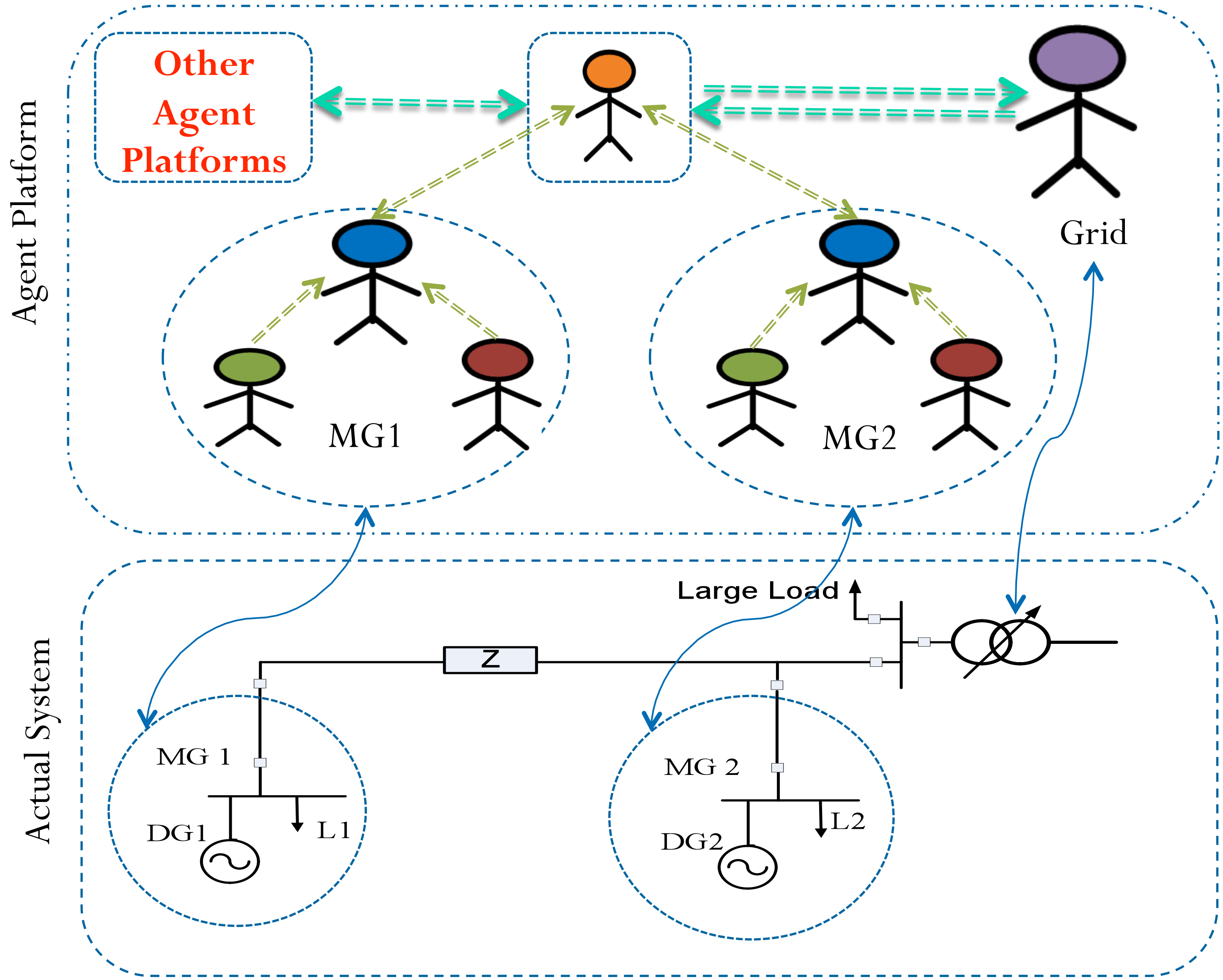
Outline of the work

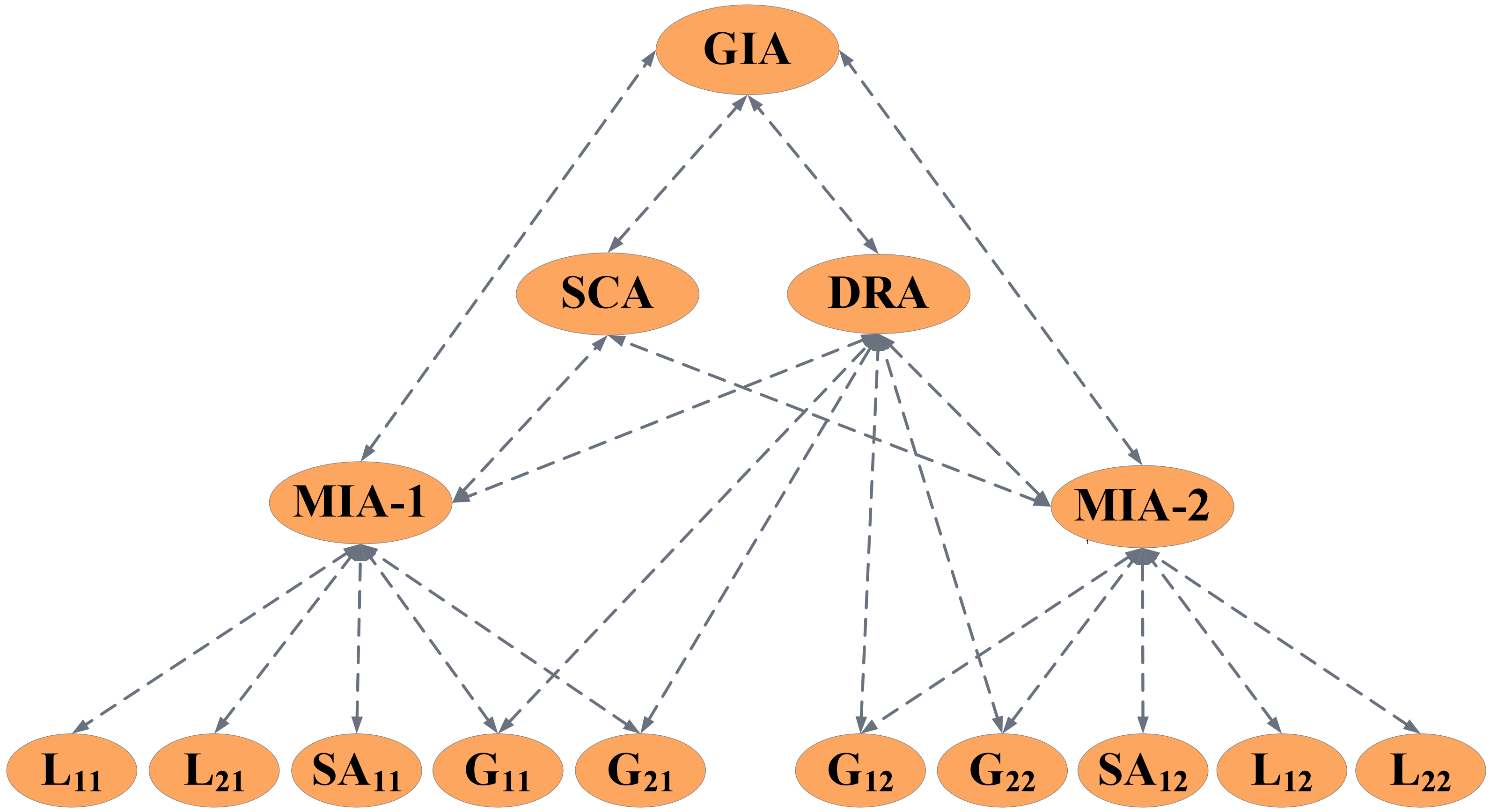
Hierarchal agent architectures
- Auction based Trading
- Developing Agents

Incorporating DSM
- Smart DR options
- Incentive Mechanisms

Incorporating Energy Storage
- Trading
- Coordinating with DR loads

Agent based Energy Trading





Hierarchal agent architecture to incorporate DR and DS

Note: L_{xy} indicates load agent number 'x' of microgrid 'y'. For example L_{21} is second load agent of microgrid-1

Incorporating DSM (DR)

- An agent called Demand Response Agent (DRA) is added to process DR requests placed by customers by negotiating with DGs.
- DRA initiates negotiation with DGs connected across the system with an offer price equal to the average of the market price range.
- DGs allot weights to each interval in the DR request based on the offer price and previous day transaction prices.
- DRA consolidates and finds the optimal duration to serve DR loads

Incentive mechanism

- A priority based incentive mechanism is proposed to fairly treat the customers participating in DR.
- "Customer with high priority index will be allowed to purchase energy from markets with low cost of generation sellers."
- Priority index is decided by the frequency and size of customer participation in DR.

Incentive mechanism

- **Priority Index (PI):**

$$PI(L_{xy}) = \frac{N}{N_{Total}} + \frac{P}{P_{Total}};\ P_{Total} \neq 0 \text{ and } N_{Total} \neq 0$$

N is the number of DR participations by L_{xy} in a day

N_{Total} is the total number of DR participations recorded in a day in the corresponding microgrid

P_{Total} is the total load participated in DR in kW in a day

P is the total participation size of L_{xy} in a day in kW

Proposed DR option

- The proposed DR option is suitable for the loads which does not require continuous supply of electricity for the specified amount of time to complete the job.
  - Low priority loads like, Washing machines, Dish washers etc.
- Proposed intelligence decides the schedule for the appliances based on the comfort levels provided by the customers and supply demand relation in the system.
- Customers shall provide staring interval (SI), dead line (DL), time required to complete the job (OT) and load size.

Incorporating Energy Storage

- The agent architecture is upgraded with Storage Agents (SAs).
- SAs participate in market through a trading broker (SCA)
- During power deficit/surplus situations, SCA participates in global auction.
- SCA enquires the storage agents regarding the status of the energy systems.
- The status information include and draining/filling abilities of the storage systems, and cost of the stored energy CSE.

Incorporating Energy Storage

- Status of the storage systems is calculated as,

$$P_{in}(i,t) = \min\left(\frac{S_{Max} - S(t-1)}{\Delta T}, P_{Max}\right)$$

$$P_{out}(i,t) = \min\left(\frac{S(t-1) - S_{Min}}{\Delta T}, P_{Max}\right)$$

  - S(t-1) is the status of a storage system during the interval (t–1) in kWh and is equal to $S\times(1-E\delta)$
  - S is the status of the system at the end of the most recent filling interval in kWh
  - δ is the self draining factor of the storage system in kWh per hour
  - E is the elapsed time from the most recent filling interval to (t-1) in hours
- The cost of stored energy is calculated as,

$$CSE(t-1) = \frac{CSE_{Re}}{(1 - E\delta)}$$

Incorporating Energy Storage

- The Participation size of SCA in market in decided by storage systems status and mismatch ΔP in the systems.
- If $\Delta P > 0$, then

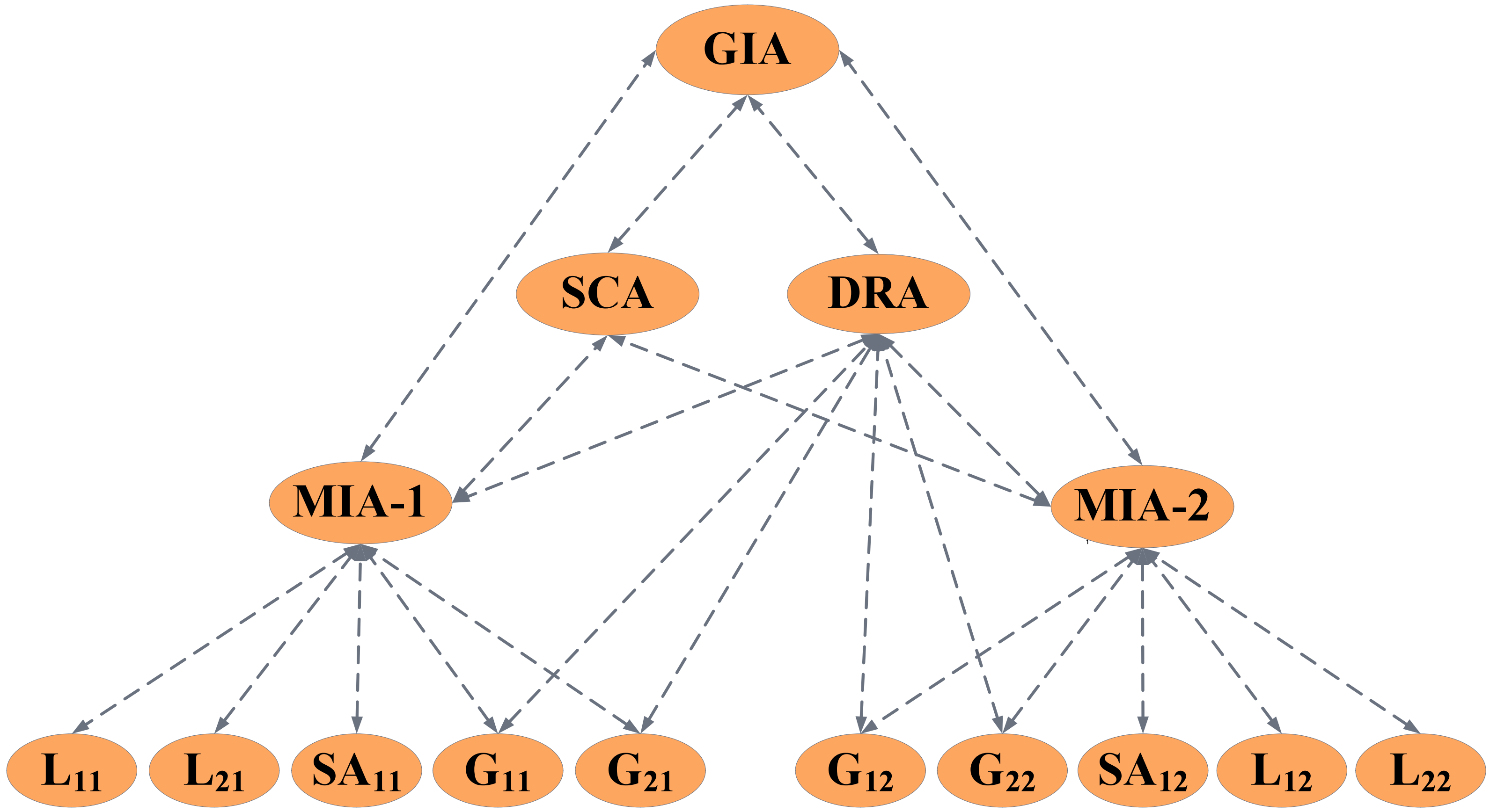
$$P_D(t) = \min\left(\Delta P, \sum_{i=1}^{B} P_{in}(i,t)\right)$$

- If $\Delta P < 0$, then

$$P_S(t) = \min\left(-\Delta P, \sum_{i=1}^{B} P_{out}(i,t)\right)$$

  - $P_D(t)$ is the amount of power to be consumed by storage systems in kW,
  - $P_S(t)$ is the amount of power to be supplied by the storage systems in kW
  - B is the total number of storages systems

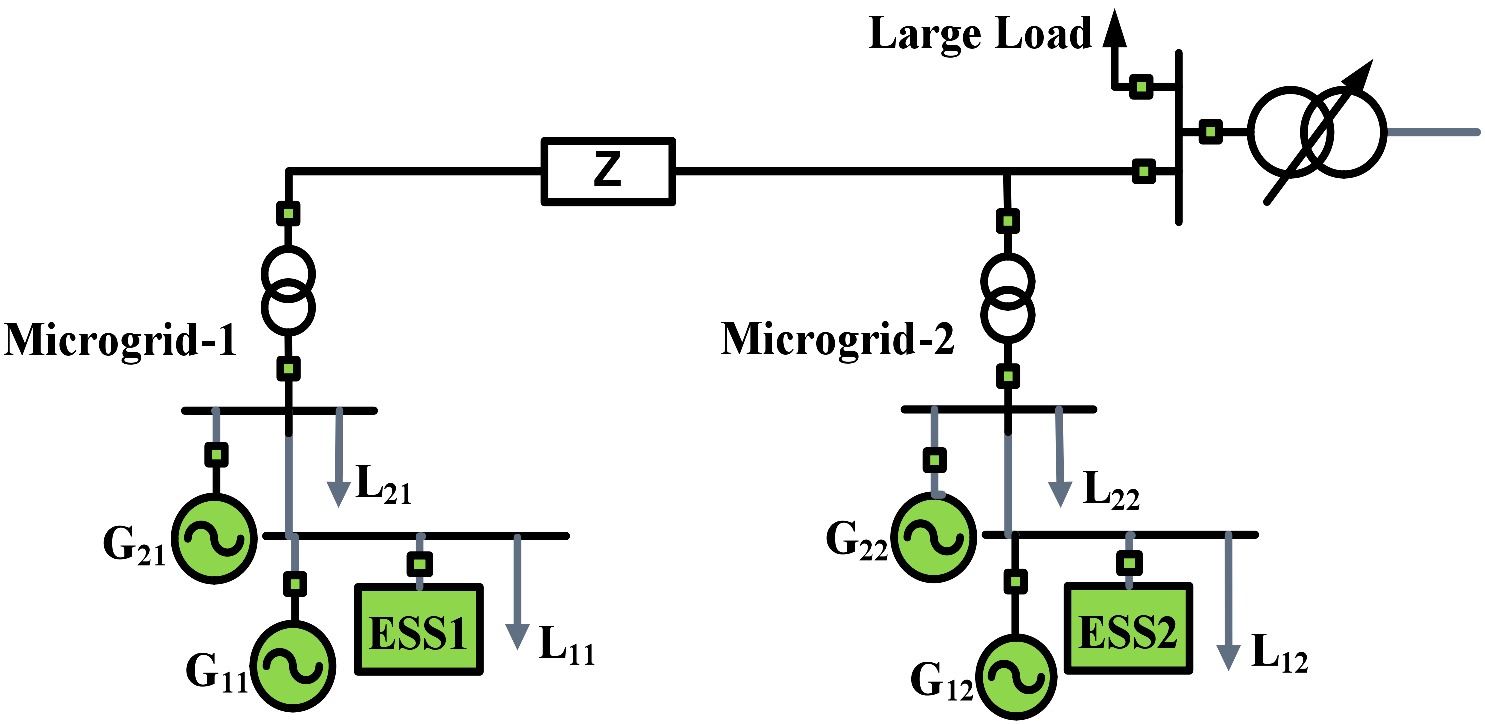
NCPRE



Hierarchal agent architecture to incorporate DR and DS

Note: L_{xy} indicates load agent number 'x' of microgrid 'y'. For example L_{21} is second load agent of microgrid-1

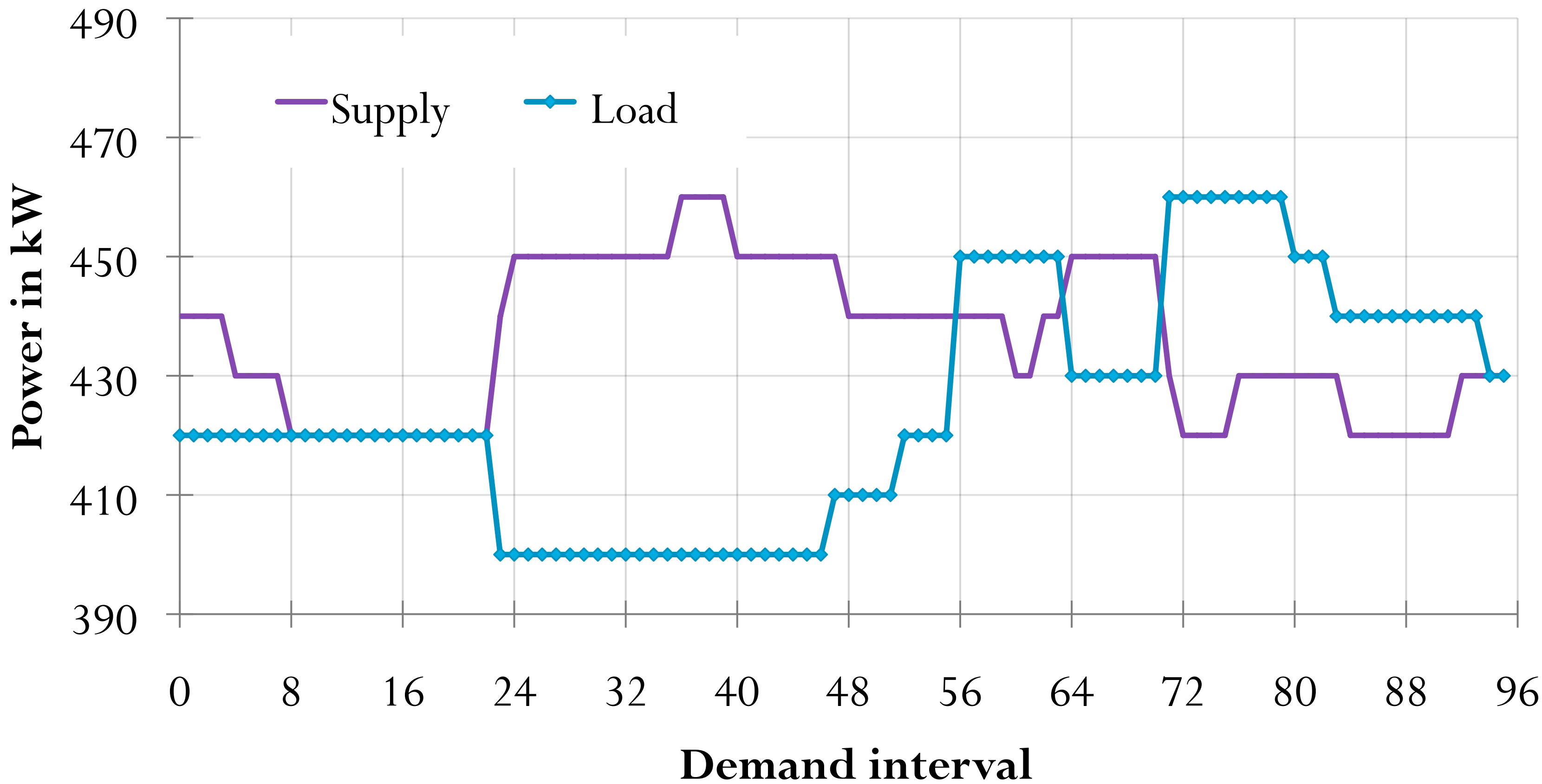
Case Study


Large Load
Z
Microgrid-1
Microgrid-2
L21
L22
G21
G22
ESS1
ESS2
L11
L12
G11
G12

Case Study

- GBP is taken as 9 cents/kWh and GSP as 13.5 cents/kWh
- For market participation, shouts must be in [GBP ,GSP]
- Each of the load agents L_{21} and L_{22} are having some low priority loads.
- The storage systems are of 40kWh rating with an operating range of 12.5% to 100% of their rated capacity. These are initially filled to 12.5% of their rated capacity at a CSE of 11.25 cents/kWh

Case study data (96 intervals)



Source: Reliance Energy, & TERI

Market simulation

DR Options

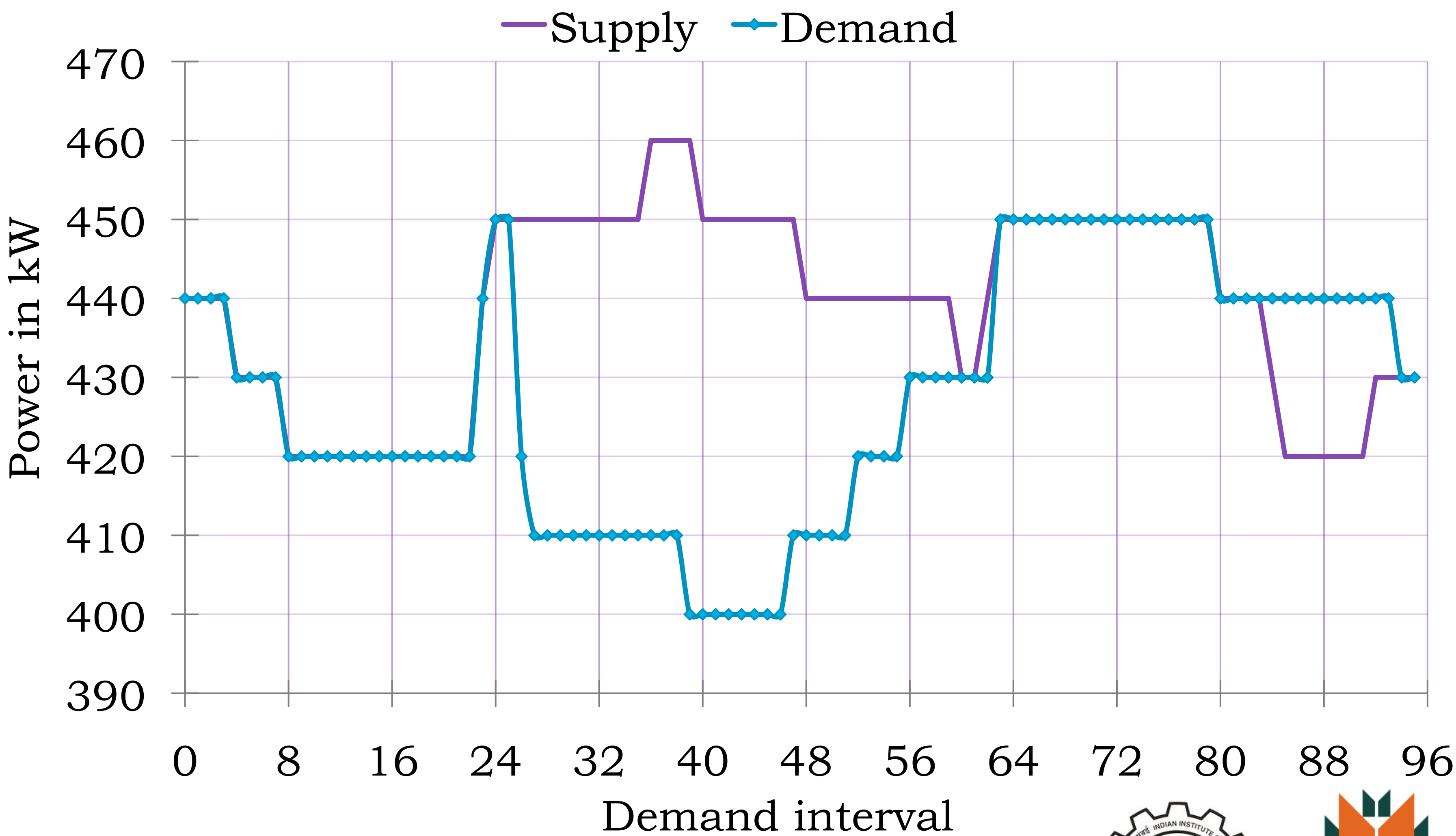
LA	SI	DL	OT	Size
L_{21}	56	71	8	20 kW
L_{22}	71	44#	12	10 kW

Optimal duration

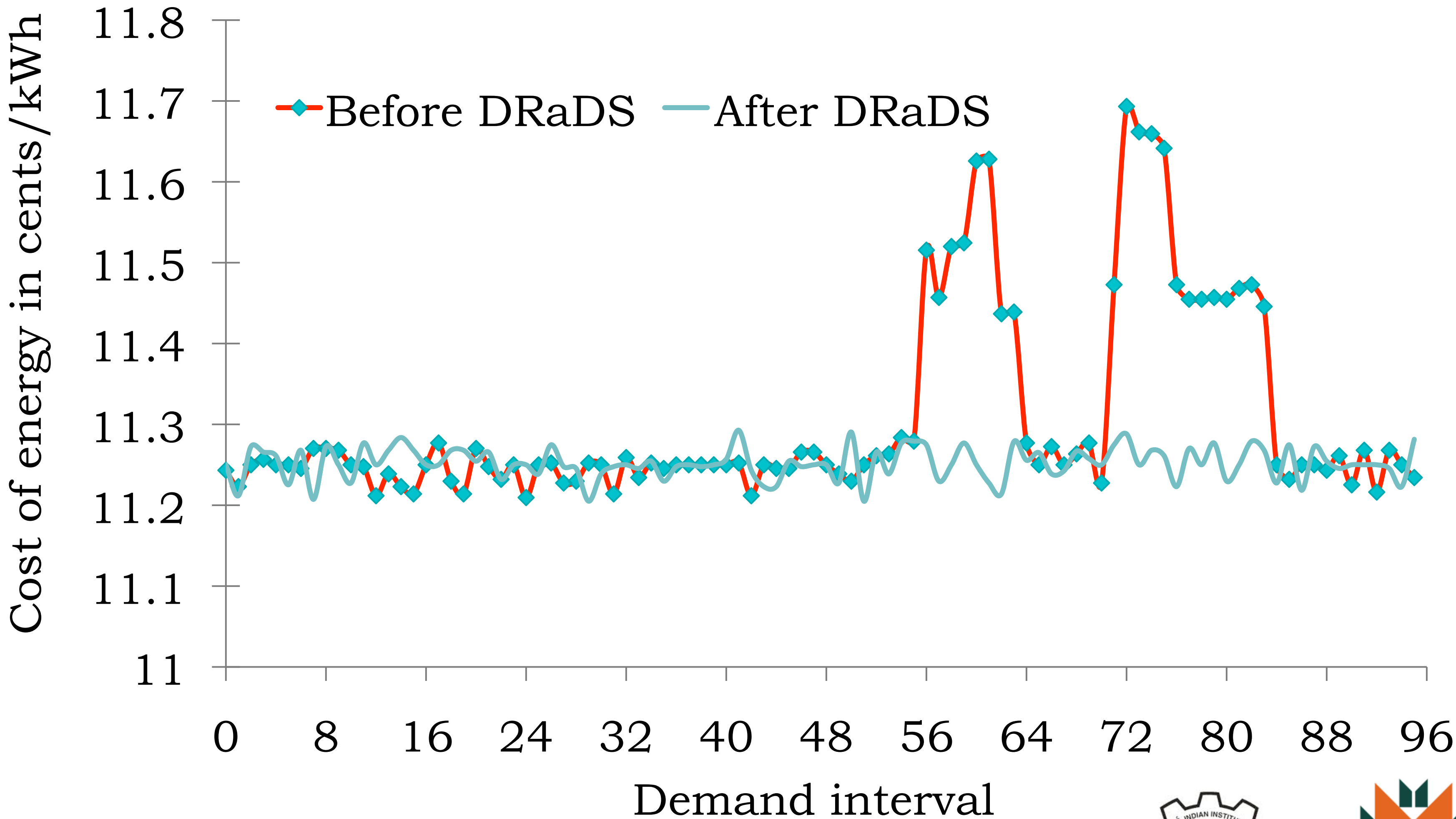
LA	Start	End	Duration	Size
L_{21}	63	70	8	20 kW
L_{22}	27#	38#	12	10 kW

#: demand interval on the following day.

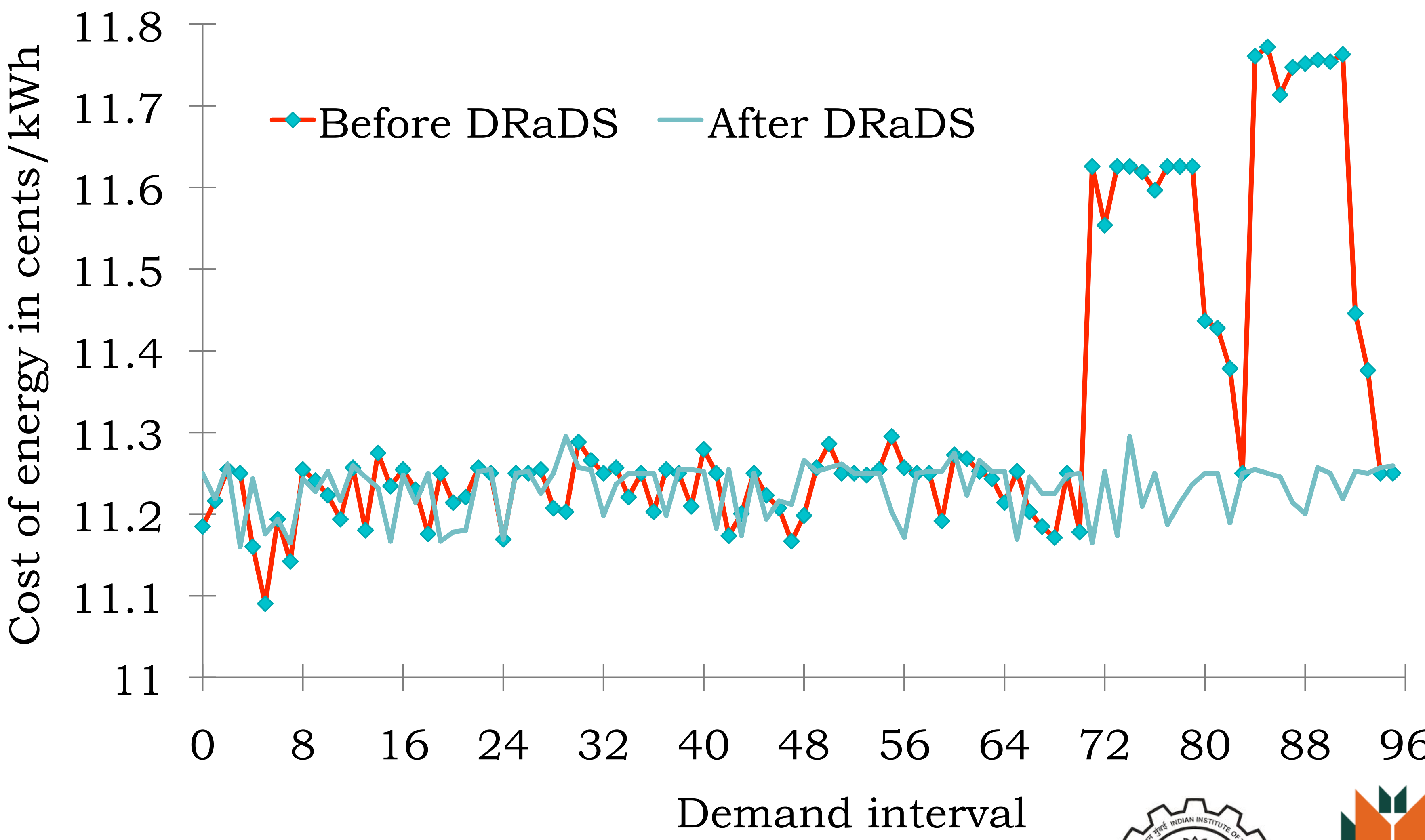
Market simulation



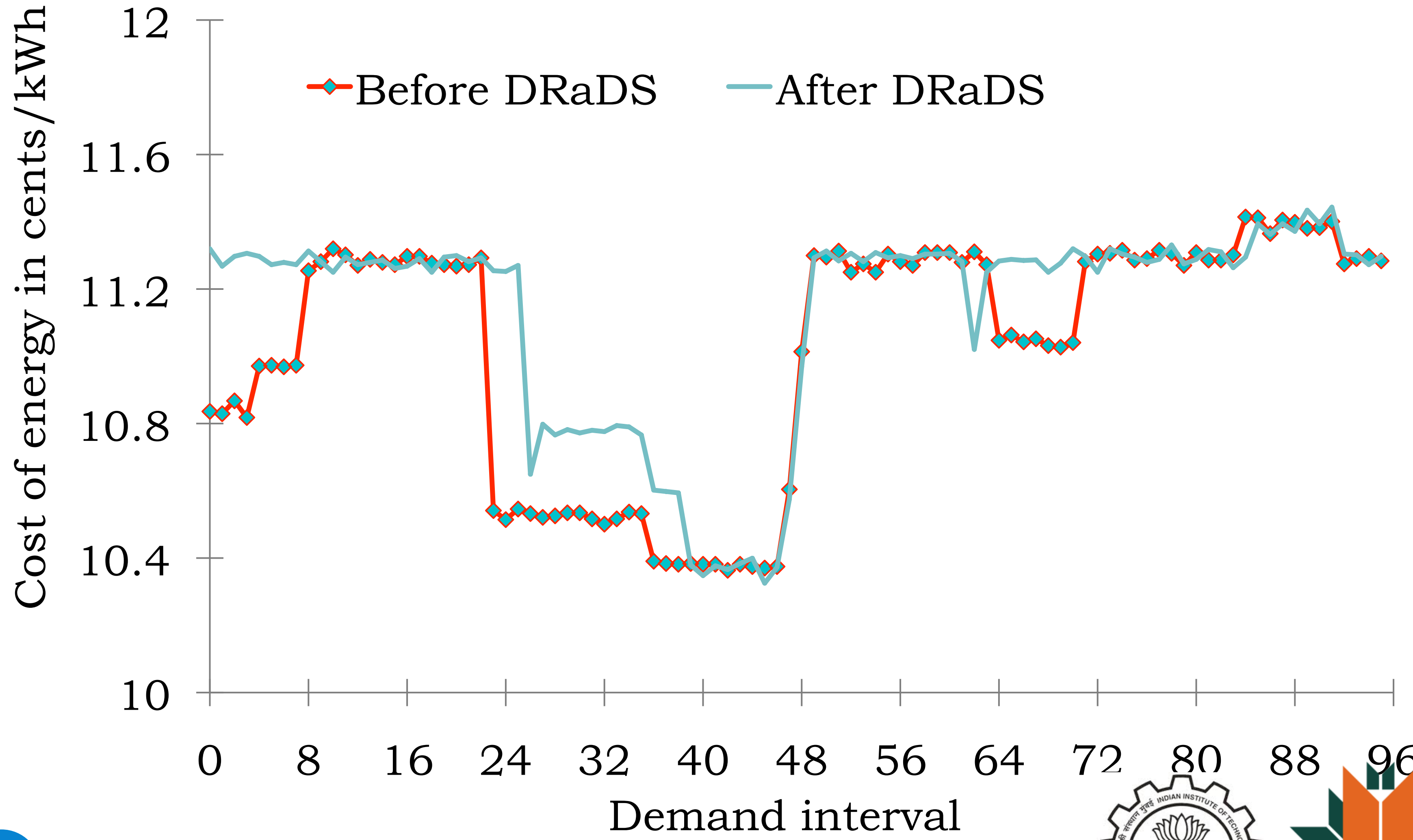
Trading history of L_{21}



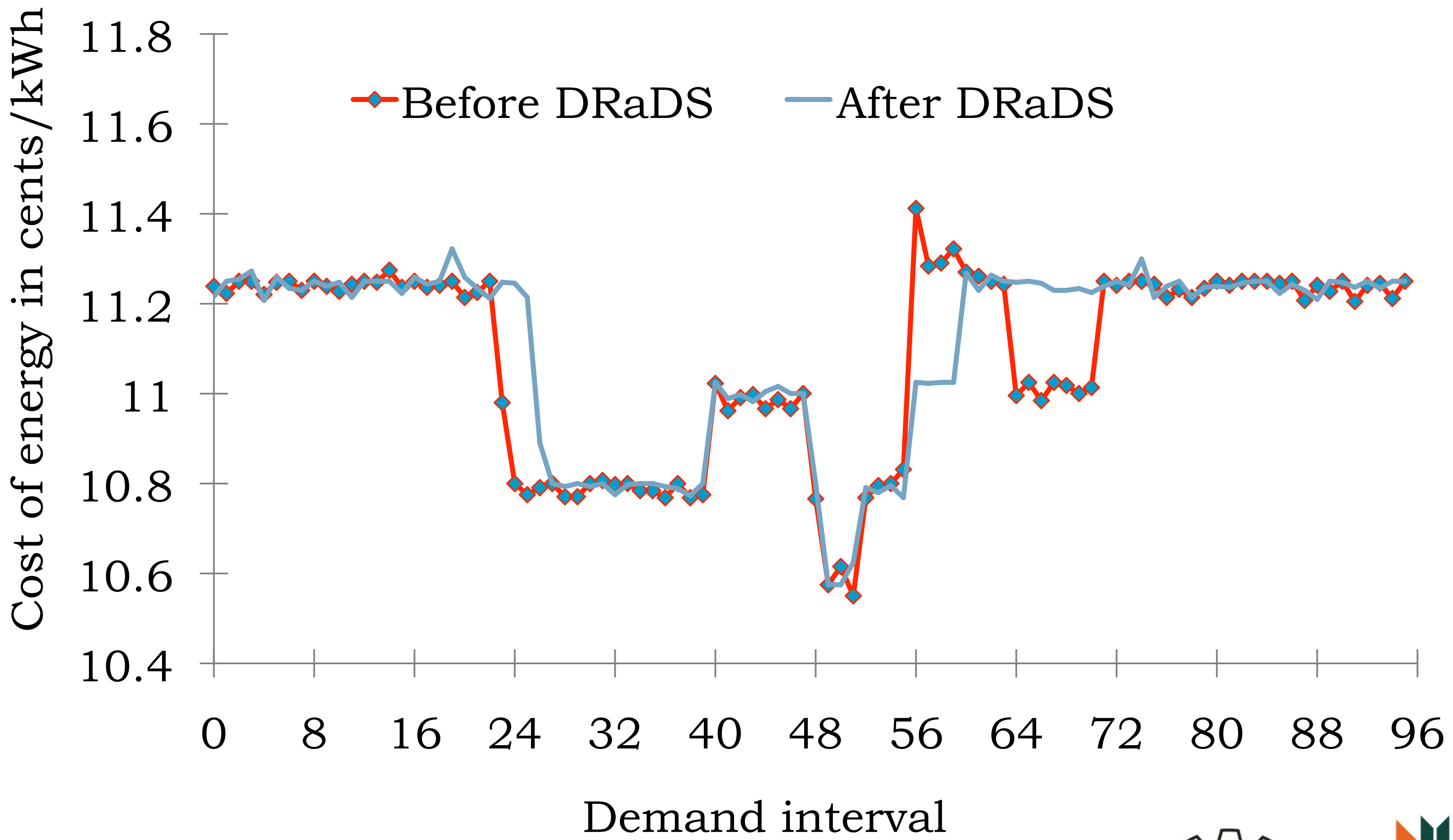
Trading history of L_{22}



Trading history of G_{21}



Trading history of G_{22}



Conclusion

- An agent based real-time energy trading framework for distributed resource management in multiple interconnected microgrids using MAS is presented.
- Customers with low priority loads are allowed to participate in DR.
- The concept of priority index, to fairly treat customers participating in DR based on size and number of times of participation, is introduced.
- From the simulation results it is clear that the proposed framework is successful in reducing the peak demand.
- It is also found that the customers with high priority index get power supply at lower cost

Acknowledgements

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Thank You

Ref: H.S.V.S.K. Nunna and S. Doolla, "Energy Management in Microgrids using Demand Response and Distributed Storage – A Multiagent Approach" *IEEE Transactions on Power Delivery*, Vol. 28, No. 2, April 2013, pp-939-947

Generation and Load data for μg-1

Block	G_{11} (kW)	G_{21} (kW)	L_{11} (kW)	L_{21} (kW)	Mismatch (kW)#
1	100	100	100	100	0
2	100	50	100	90	–40
3	100	50	100	90	–40
4	100	50	100	90	–40
5	100	70	100	50	+20
6	100	50	100	50	0
7	100	90	100	50	+40
8	80	90	100	50	+20
9	80	100	100	50	+30

#: '+' sign indicates surplus and '–' sign indicates deficit

Generation and Load data for µg-2

Block	G12 (kW)	G22 (kW)	L12 (kW)	L22 (kW)	Mismatch (kW) #
1	100	100	100	100	0
2	100	100	100	100	0
3	100	100	100	80	+20
4	100	100	100	70	+30
5	100	50	100	70	–20
6	100	100	100	50	+50
7	100	100	100	50	+50
8	100	80	100	100	–20
9	100	80	100	100	–20

#: '+' sign indicates surplus and '–' sign indicates deficit

Trading history of μg-1 w/o DRaDS

Blk.	Market	G11* (Price)	G21* (Price)	L11* (Price)	L21* (Price)
1	Local	100/(11.20)	100/(11.23)	100/(11.23)	100/(11.20)
	Global	-	-	-	-
2	Local	100/(11.18)	50/(11.18)	100/(11.18)	50/(11.18)
	Global	-	-	-	40/(13.5)
3	Local	100/(11.23)	50/(11.25)	100/(11.23)	50/(11.25)
	Global	-	-	-	40/(12.80)
4	Local	100/(11.23)	50/(11.23)	100/(11.23)	50/(11.23)
	Global	-	-	-	40/(12.06)
5	Local	100/(11.25)	50/(11.23)	100/(11.23)	50/(11.25)
	Global	-	20/(11.20)	-	-
6	Local	100/(11.20)	50/(11.20)	100/(11.20)	50/(11.20)
	Global	-	-	-	-
7	Local	100/(11.27)	50/(11.23)	100/(11.27)	50/(11.23)
	Global	-	40/(9.0)	-	-
8	Local	80/(11.20)	70/(11.20)	100/(11.20)	50/(11.20)
	Global	-	20/(11.23)	-	-
9	Local	80/(11.18)	70/(11.18)	100/(11.18)	50/(11.18)
	Global	-	30/(10.13)	-	-

*: Units for market share are in kW, Price in cents/kWh

Trading history of µg-2 w/o DRaDS

Blk.	Market	G_{12}* (Price)	G_{22}* (Price)	L_{12}* (Price)	L_{22}* (Price)
1	Local	100/(11.18)	100/(11.25)	100/(11.18)	100/(11.25)
	Global	-	-	-	-
2	Local	100/(11.23)	100/(11.18)	100/(11.18)	100/(11.23)
	Global	-	-	-	-
3	Local	100/(11.19)	80/(11.19)	100/(11.19)	80/(11.19)
	Global	-	20/(12.11)	-	-
4	Local	100/(11.20)	70/(11.23)	100/(11.20)	70/(11.23)
	Global	-	30/(11.59)	-	-
5	Local	100/(11.27)	50/(11.18)	100/(11.18)	50/(11.27)
	Global	-	-	-	20/(11.20)
6	Local	100/(11.23)	50/(11.19)	100/(11.23)	50/(11.19)
	Global	-	50/(9.0)	-	-
7	Local	100/(11.27)	50/(11.23)	100/(11.27)	50/(11.23)
	Global	-	50/(9.0)	-	-
8	Local	100/(11.18)	80/(11.18)	80/(11.18)	100/(11.18)
	Global	-	-	20/(11.23)	-
9	Local	100/(11.25)	80/(11.25)	80/(11.25)	100/(11.25)
	Global	-	-	20/(10.69)	-

*: Units for market share are in kW, Price in cents/kWh

Trading history of μg-1 with DRaDS

Blk.	1		2		3		4		5		6			7			8		9	
Mkt.	Local	Global	Local	Global	Local	Global	Local	Global	Local	Global	Local	Global	DR	Local	Global	DR	Local	Global	Local	Global
G_{11}*	100/11.23	-	100/11.20	-	100/11.25	-	100/11.23	-	100/11.27	-	100/11.30	-	-	100/11.30	-	-	80/11.22	-	80/11.18	-
G_{21}*	100/11.23	-	50/11.18	-	50/11.25	-	50/11.23	-	50/11.20	20/11.23	50/11.30	-	-	50/11.20	20/9.45	20/11.25	70/11.22	20/11.25	70/11.18	30/11.26
L_{11}*	100/11.23	-	80/11.20	20/11.25	80/11.25	20/11.27	80/11.23	20/11.26	100/11.20	-	100/11.30	-	-	100/11.30	-	-	100/11.22	-	100/11.18	-
L_{21}*	100/11.23	-	70/11.18	-	70/11.25	-	70/11.23	-	50/11.27	20/11.24	50/11.30	-	20/11.25	50/11.20	-	20/11.25	50/11.22	-	50/11.18	-
SA_{11}*#	-	-	-	—10/11.25	-	-	-	10/11.26	-	—10/11.25	-	10/10.89	-	-	10/10.01	-	-	-	-	10/11.25

*: Units for market share are in kW, Price in cents/kWh, #: '+' indicates filling and '—' indicates draining

Trading history of µg-2 with DRaDS

Blk.	1		2		3		4			5			6			7			8			9		
Mkt.	Local	Global	Local	Global	Local	Global	Local	Global	DR	Local	Global	DR	Local	Global	DR	Local	Global	DR	Local	Global	DR	Local	Global	DR
G12* (Price)	100/11.24	-	100/11.23	-	100/11.25	-	100/11.20	-	-	100/11.27	-	-	100/11.23	-	-	100/11.27	-	-	100/11.18	-	-	100/11.25	-	-
G22* (Price)	100/11.24	-	100/11.2	-	80/11.25	20/11.27	70/11.23	30/11.26	-	50/11.18	-	-	50/11.19	30/10.27	20/11.25	50/11.23	50/9.20	-	80/11.18	-	-	80/11.25	-	-
L12* (Price)	100/11.24	-	100/11.20	-	100/11.25	-	100/11.20	-	-	100/11.18	-	-	100/11.23	-	-	100/11.27	-	-	80/11.18	20/11.23	-	80/11.25	20/11.26	-
L22* (Price)	100/11.24	-	100/11.23	-	80/11.25	-	70/11.23	-	-	50/11.27	20/11.24	-	50/11.19	-	-	50/11.23	-	-	100/11.18	-	-	100/11.25	-	-
SA_{12}*# (Price)	-	-	-	–10/11.25	-	-	-	-	-	-	–10/11.24	-	-	10/10.94	-	-	10/9.9	-	-	-	-	-	-	-

*: Units for market share are in kW, Price in cents/kWh, #: '+' indicates filling and '-–' indicates draining