Optimal Demand Response Bidding and Pricing Mechanism: Application for a Virtual Power Plant

Authors:
Ashot Mnatsakanyan
Scott Kennedy

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Outline

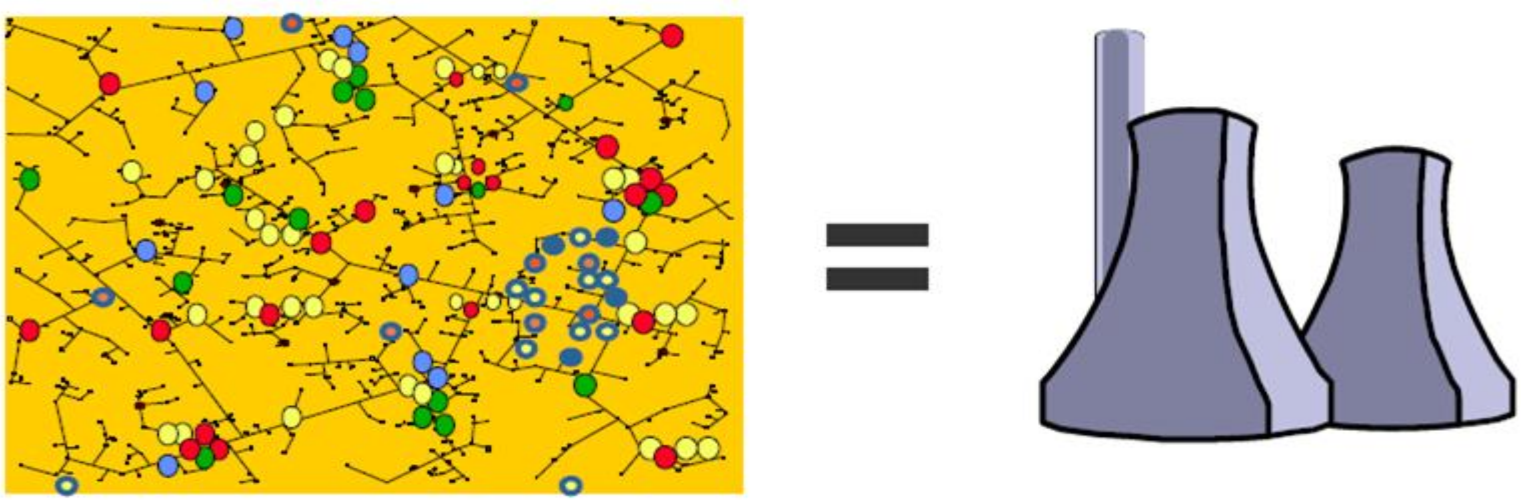
- Introduction and Motivation
- Demand Response and Proposed Market Structures
- Results
- Conclusions
- Future Work

Introduction

Increased presence of small and medium scale distributed variable generation

➢ Potential to harm the system stability

✓One solution is the creation of Virtual Power Plant



Introduction

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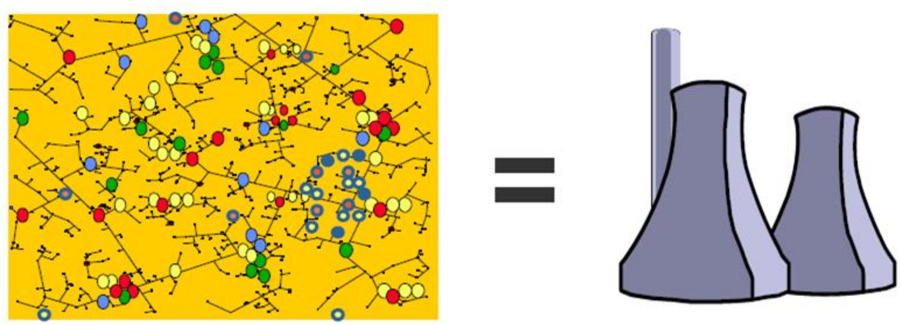
Virtual Power Plant (VPP) Definition

“A Virtual Power Plant (VPP) aggregates the capacity of many diverse Distributed Energy Resources (DERs), it creates a single operating profile from a composite of the parameters characterizing each DERs and can incorporate the impact of the network on aggregate DERs output. A VPP is a flexible representation of a portfolio of DERs that can be used to make contracts in the wholesale market and to offer services to the system operator” (FENIX)



Motivation

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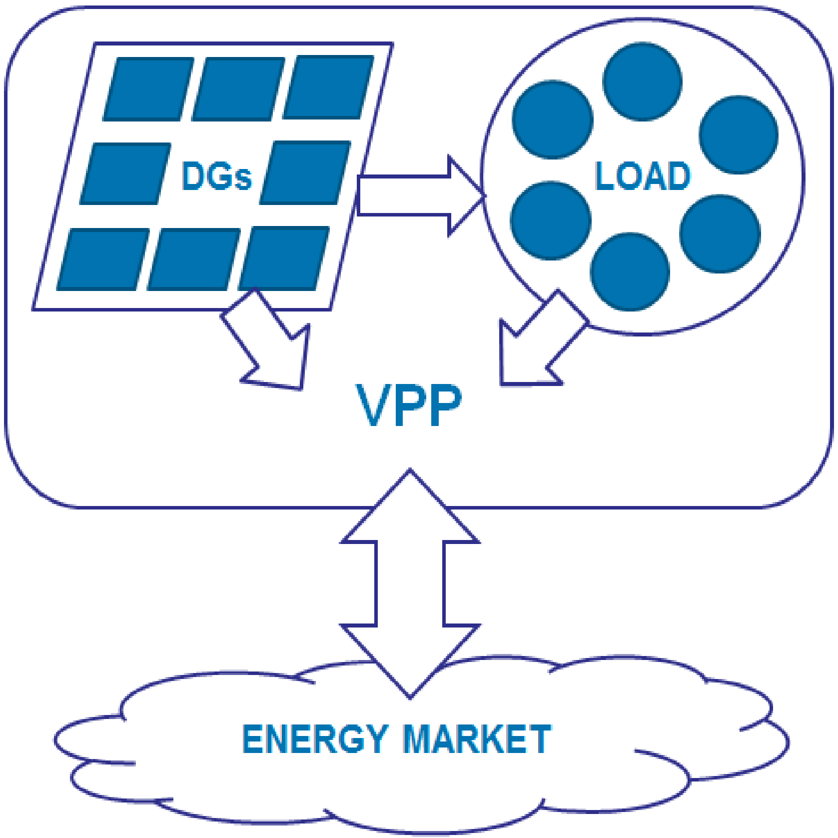
Questions

- How can a VPP participate in current energy markets?
- What are the benefits of demand side?
- How can the demand side become an active participant through VPPs?
- How to integrate demand side into VPP systems?

Motivation

VPPs can also incorporate loads

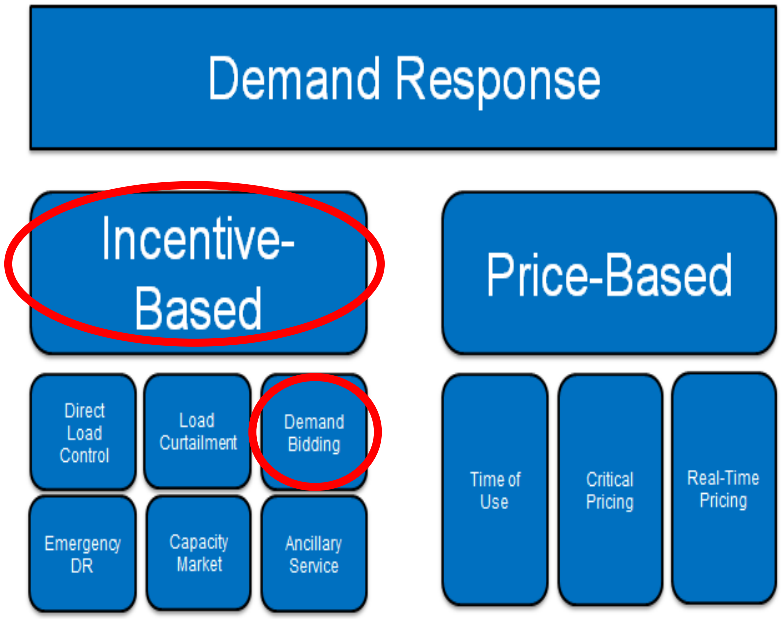
- Non-flexible load
- Flexible loads: demand response (DR) providers



Proposed DR Integration Scenario

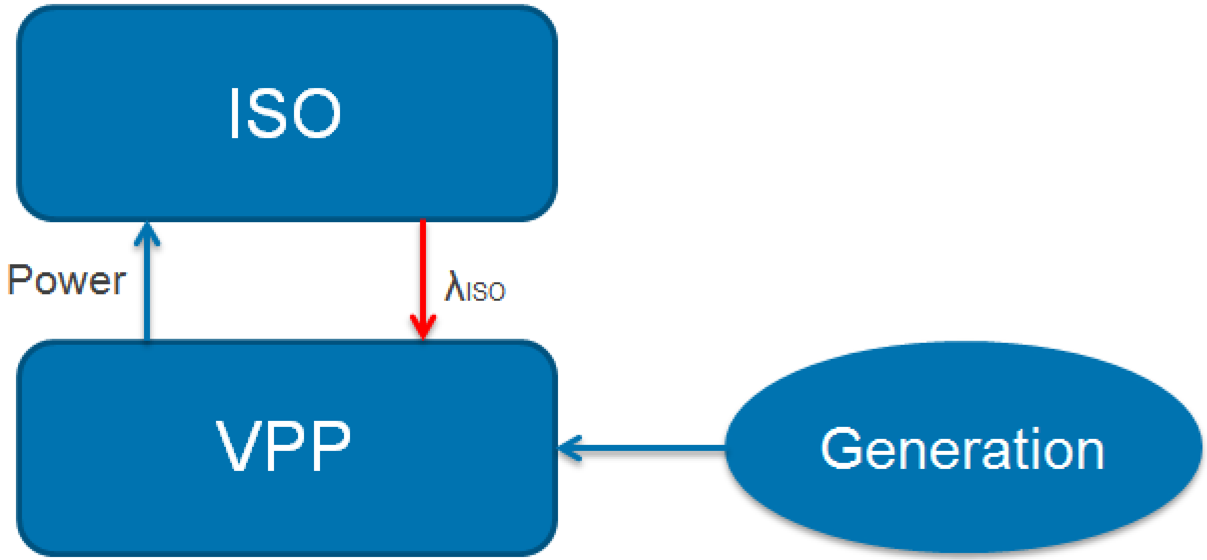
1) Price-based demand response

2) Incentive-based demand response



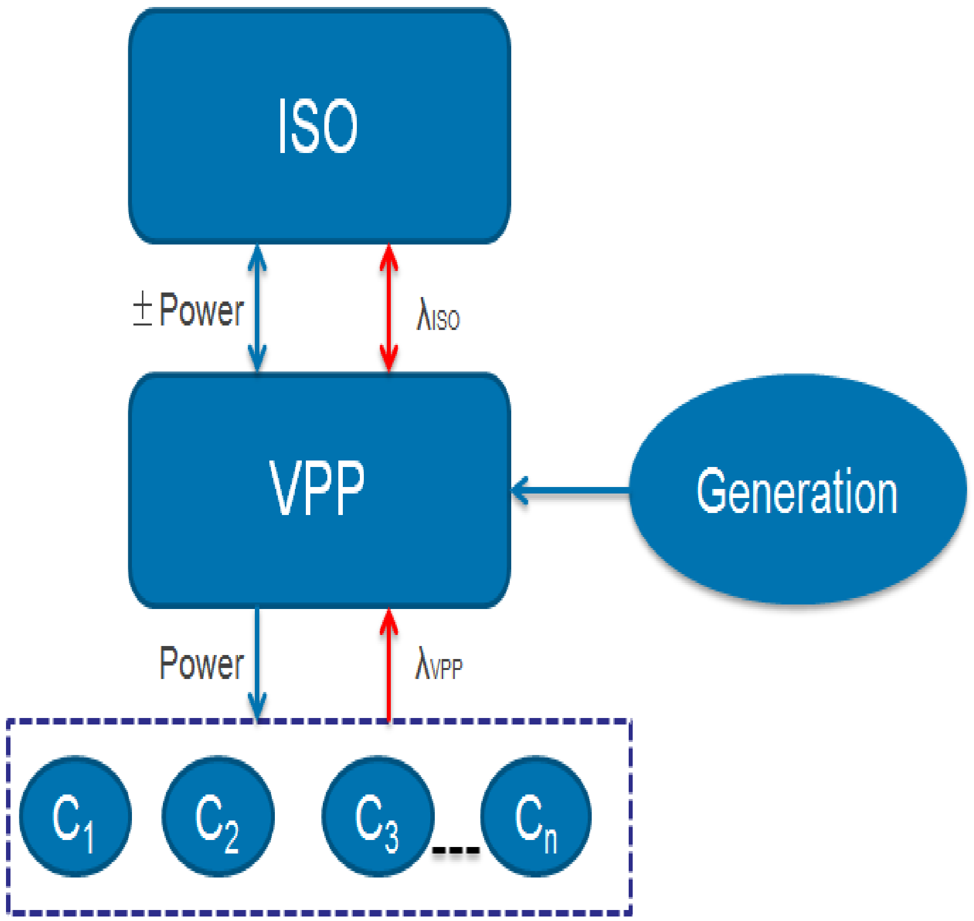
Basic Scenario

- VPP aggregates DGs
- Sells power to wholesale market



Basic Scenario With Loads

- VPP aggregates DGs and loads
- Sells power to internal load
- Purchases power in case of internal generation shortage
- Sells power in case of excess generation



Scenario with DGs and DR

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Proposed VPP Structure

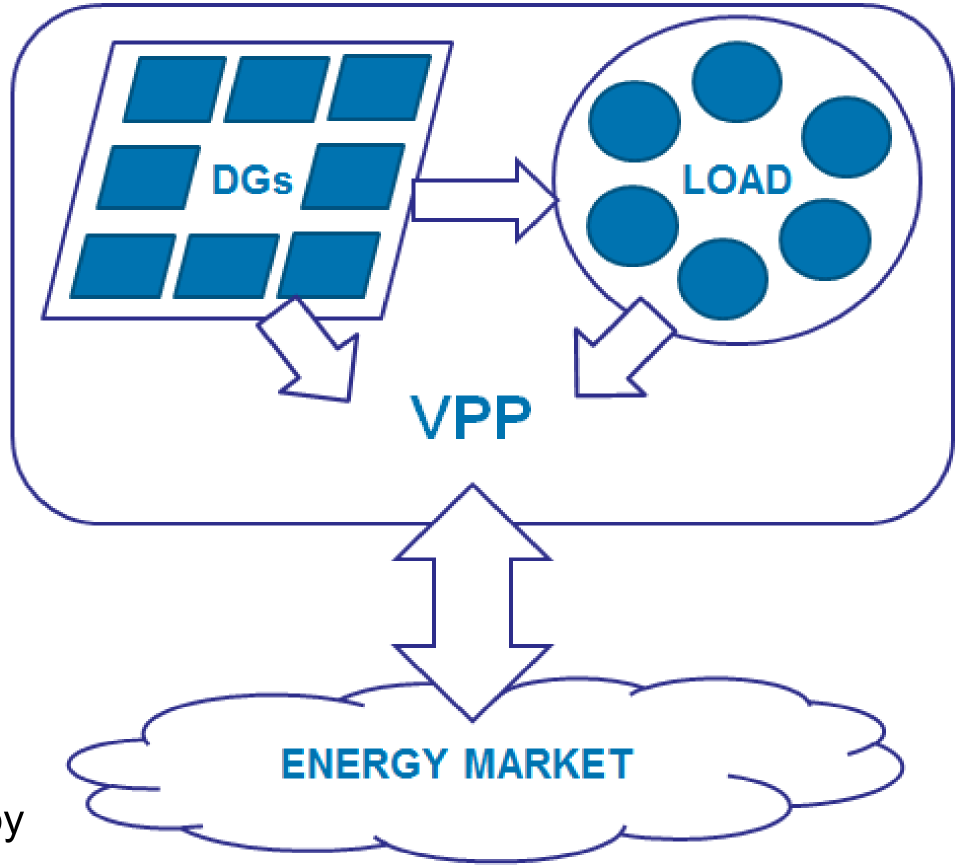
- Solar and wind generation
- Dispatchable generator
- Contracted flexible load

Market Interactions

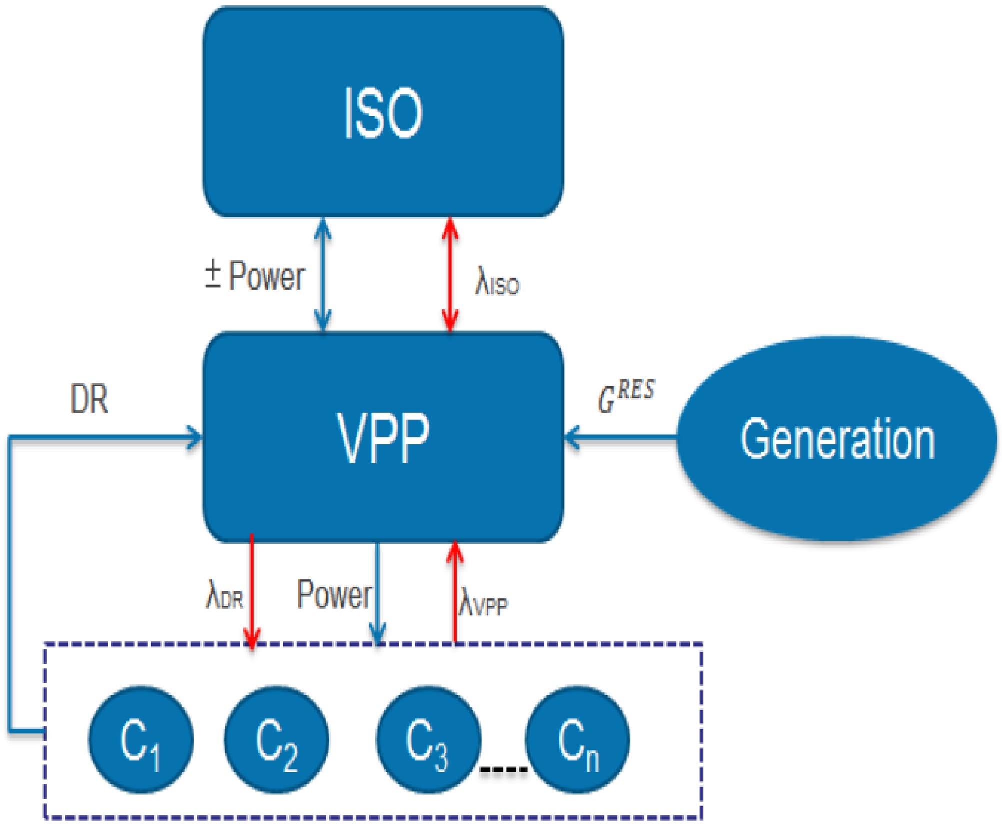
- VPP sells power to the internal load with a fixed price (=LCOE)
- VPP purchases power from external market in case of internal generation shortage
- VPP sells power to the external market in case of excess generation

Demand Response

- Consumers are enabled to bid “negawatts” by the call of VPP
- VPP buys the aggregated “negawatts” in order to sell more (buy less) power from external market



Proposed Market Structure and Interactions



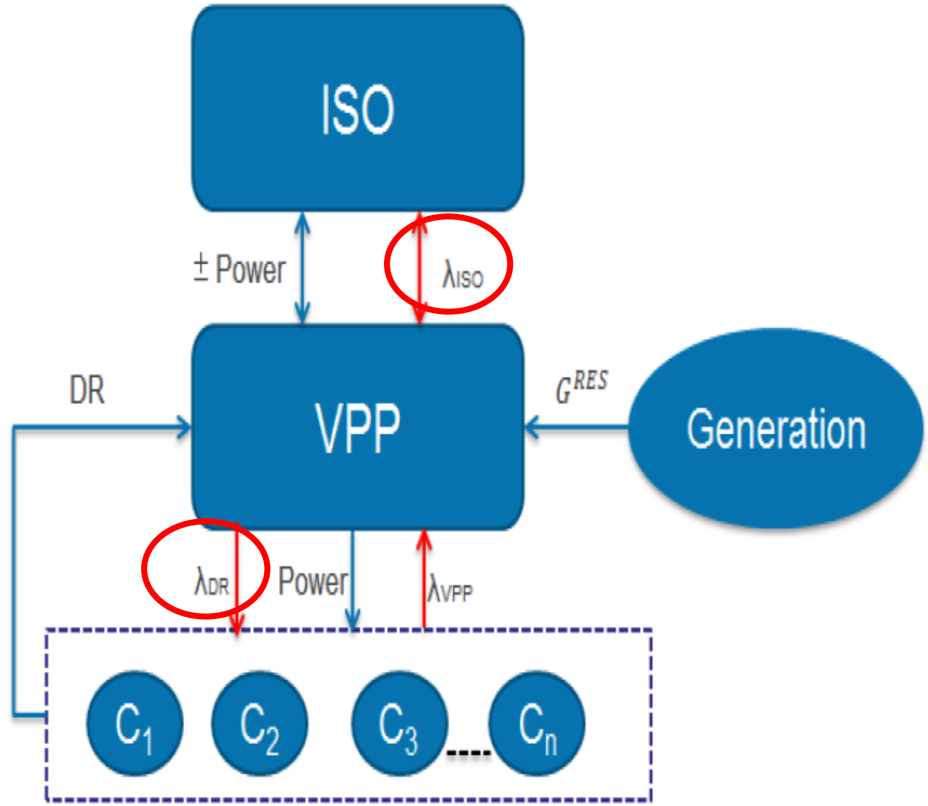
VPP Market Structure

Profits

- Selling power to the internal consumers with the bilaterally contracted price
- Selling the excess power into the external market

Expenses

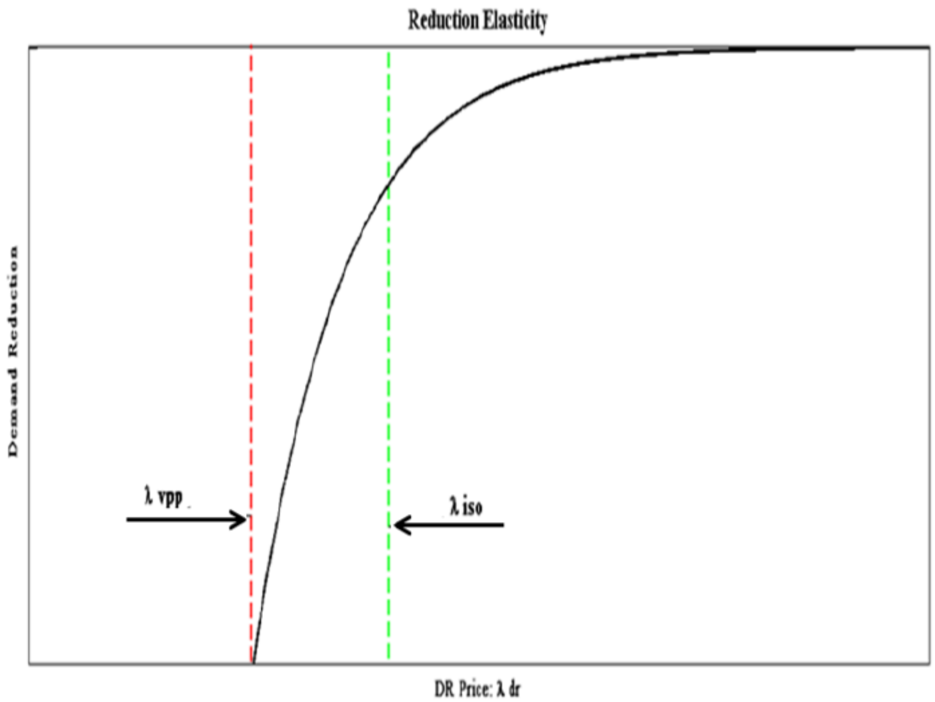
- Purchase of power from the external market
- Purchase of DR offered by the internal load
- Operating the dispatchable generator

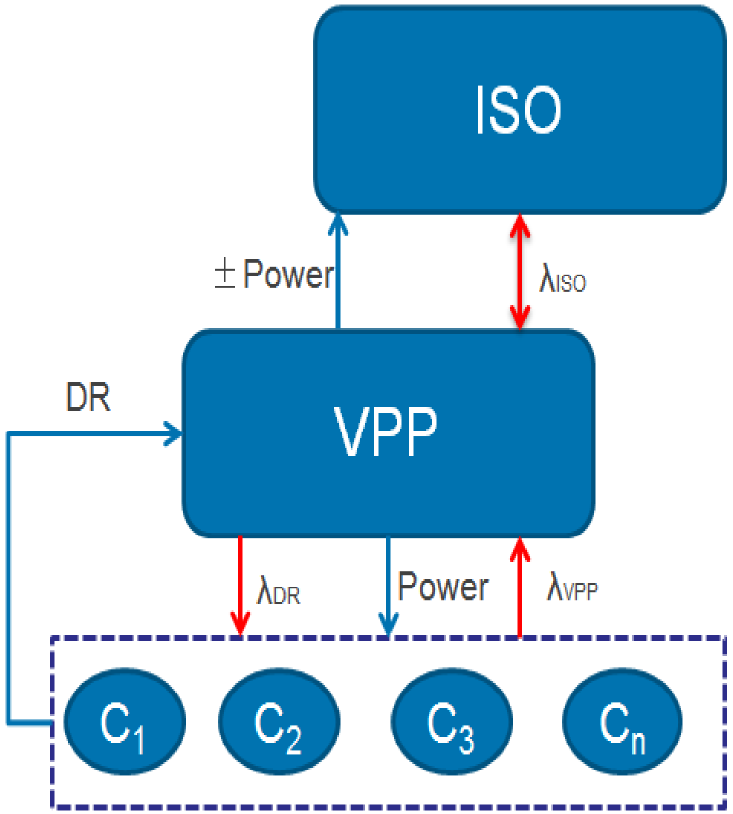


Demand Response Analysis

- Elasticity

$$R = D \times \left(1 - e^{-\alpha(\lambda_{DR} - \lambda_{VPP})}\right)$$

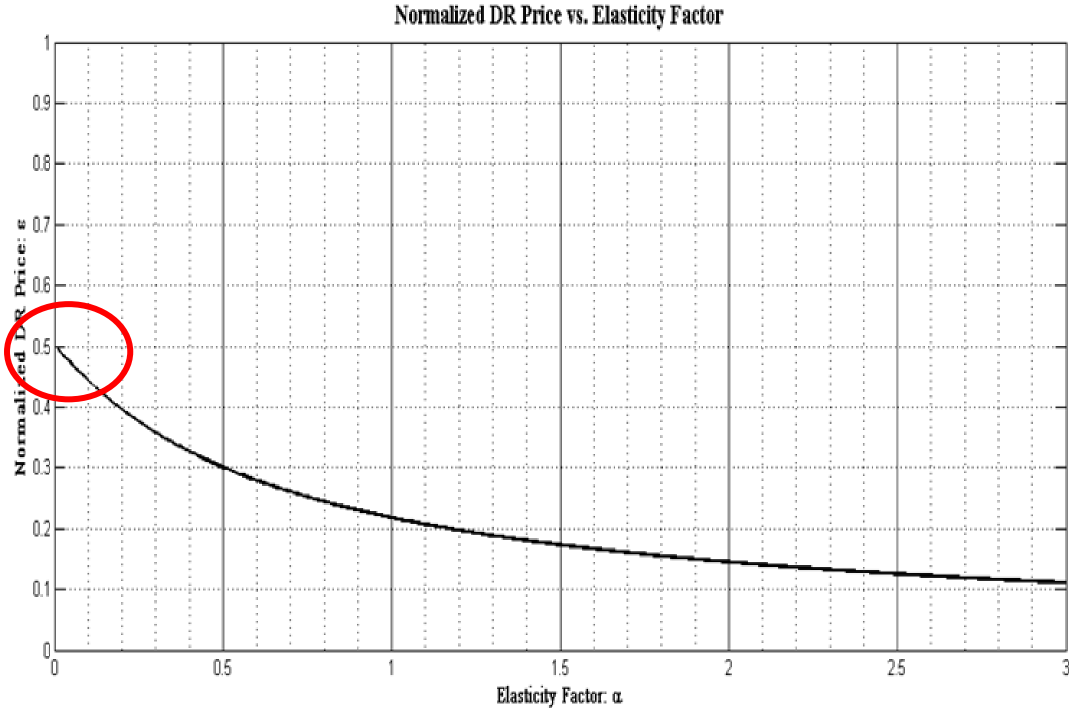




Demand Response Analysis

$$P(R) = R \times (\lambda_{ISO} - \lambda_{DR})$$ → **VPP Profit**

$$\varepsilon = \frac{\lambda_{DR}^{*} - \lambda_{VPP}}{\lambda_{ISO} - \lambda_{VPP}}$$ → **Normalized DR price**

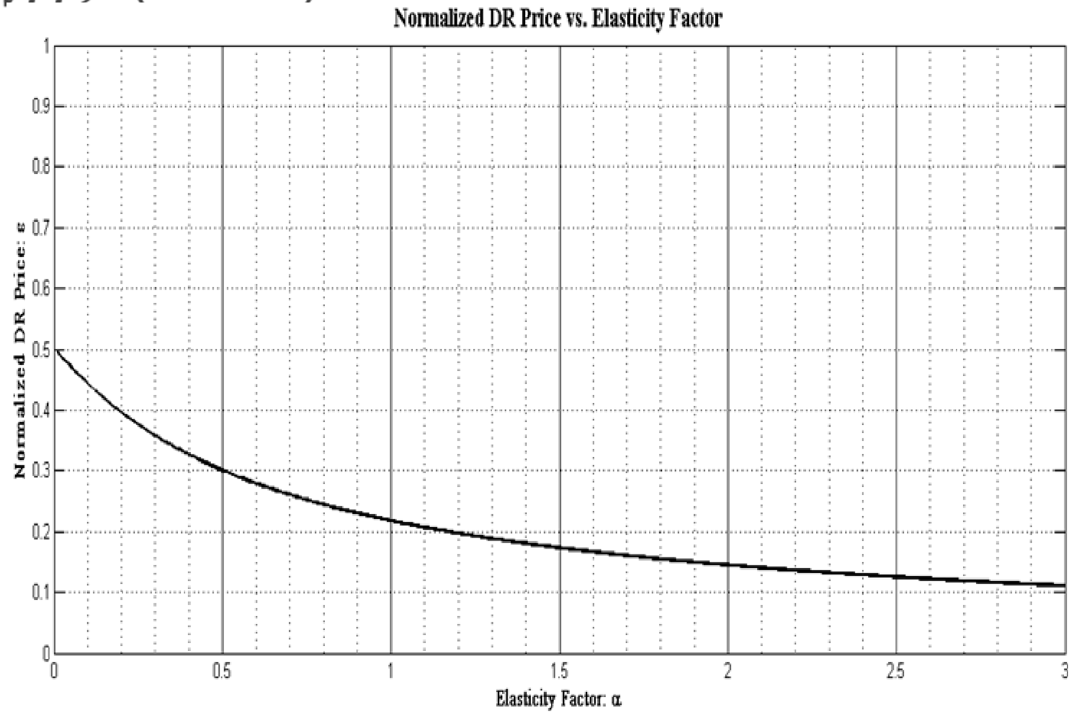


Demand Response Analysis

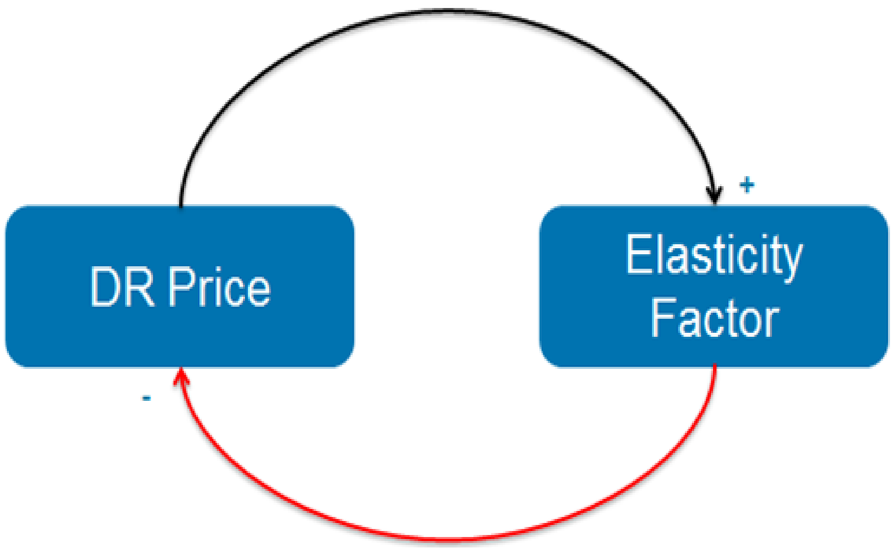
First-order through a Taylor series expansion when $\boldsymbol{\alpha}$ approaches zero

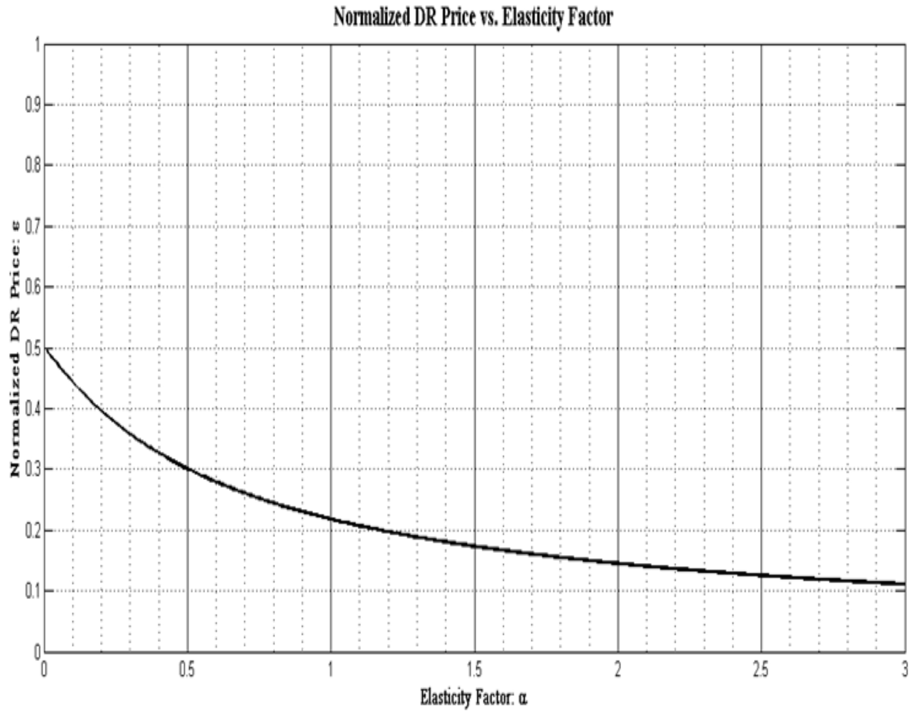
$$P(R) \cong \alpha D(\lambda_{ISO} - \lambda_{VPP})\,(\lambda_{ISO} - \lambda_{DR})$$

$$P(R) \cong \alpha D(\lambda_{ISO} - \lambda_{VPP})^2(\varepsilon - \varepsilon^2) \longrightarrow \varepsilon = 0.5$$

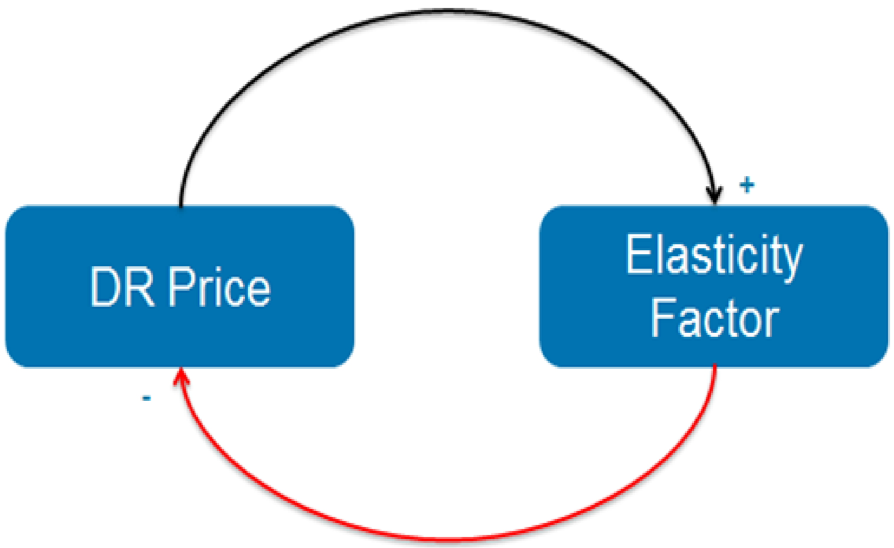


Demand Response Analysis



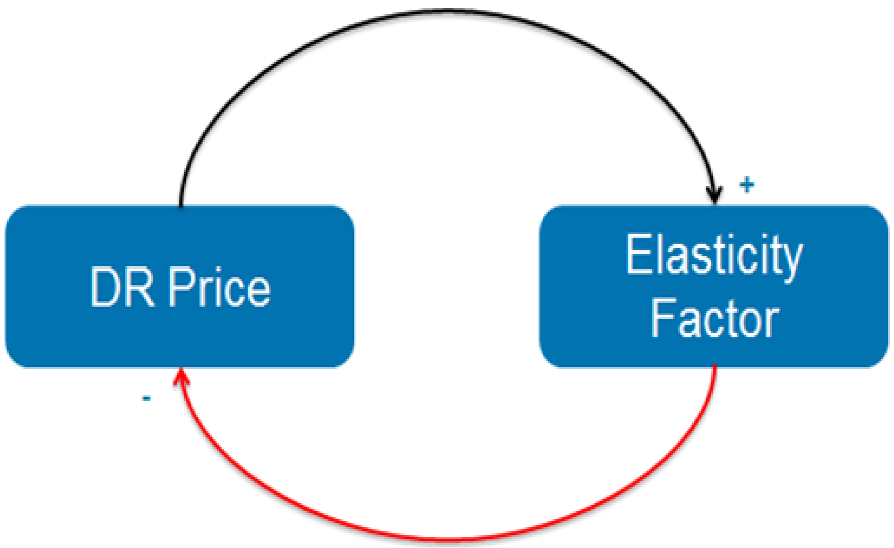


Demand Response Analysis



An increase in the elasticity factor across all customers will encourage the VPP to reduce the DR price to extract more profit, which will discourage the incentive for further increases in demand responsiveness

Demand Response Analysis



As with any dynamic system, if there is delay in the response to a control action - in this case the change in elasticity due to a change in the average DR price - there will be a tendency for the system to oscillate.

VPP Model

$$\textit{Maximize Profit}$$

$$\sum_{t=1}^{24} (\lambda_t^{ISO} Bid_t - \lambda_t^{DR} R_t + \lambda_t^{VPP} D_t - E_t^{conv} - y_t S)$$

s.t.

Dispatchable generator constraints:

$$E_t^{conv} = a \cdot x_t + b \cdot G_t + c \cdot G_t^2$$
$$x_t \cdot G^{min} \le G_t \le x_t \cdot G^{max}$$
$$-Ramp \le G_t - G_{t-1} \le Ramp$$
$$x_t - x_{t-1} \le y_t$$

Energy balance constraint:

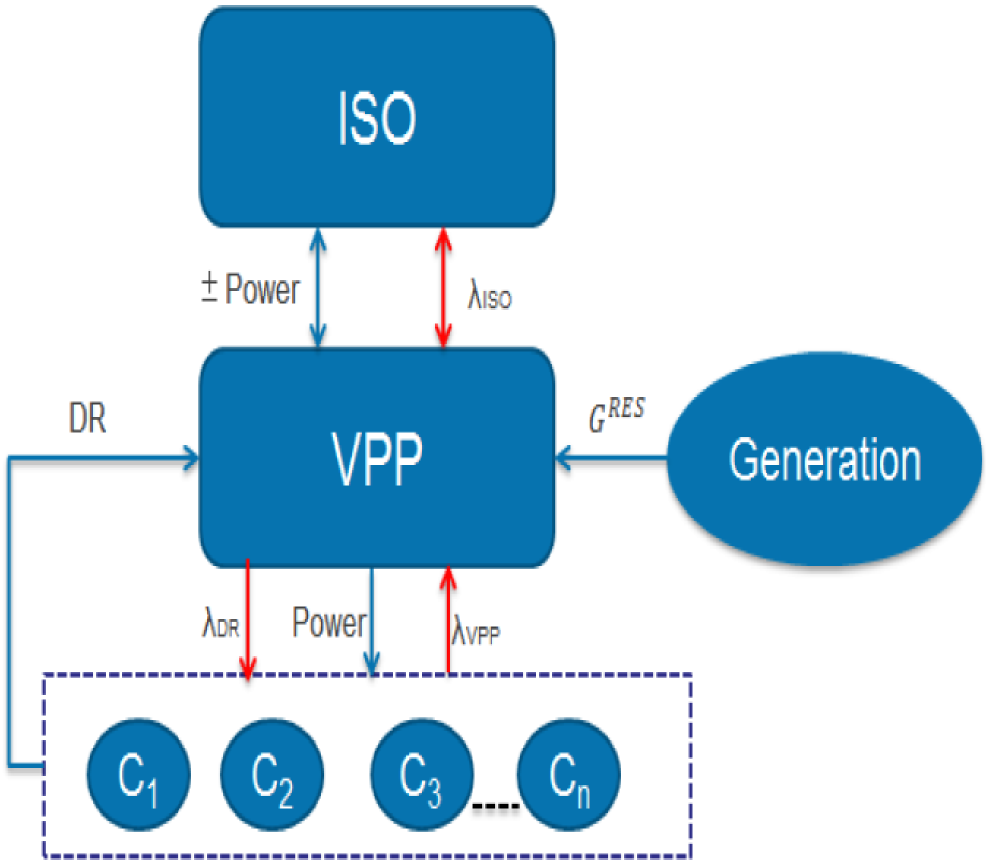
$$G_t + W_t + S_t = D_t + Bid_t$$

Energy delivery constraints:

$$\sum_{t=1}^{24} D_t = \sum_{t=1}^{24} \sum_{i=1}^{N} (L_{it} - R_{it})$$
$$D_t \ge 0.9 \sum_i^N (L_{it} - R_{it})$$
$$D_t \le 1.1 \sum_i^N (L_{it} - R_{it})$$

DR constraints:

$$R_{it} = L_{it} \cdot (1 - e^{-\propto_{it}(\lambda_t^{DR} - \lambda_t^{VPP})})$$
$$\lambda_t^{VPP} \le \lambda_t^{DR} \le \lambda_t^{ISO}$$
$$\sum_i^N R_{it} \ge R^{min}$$



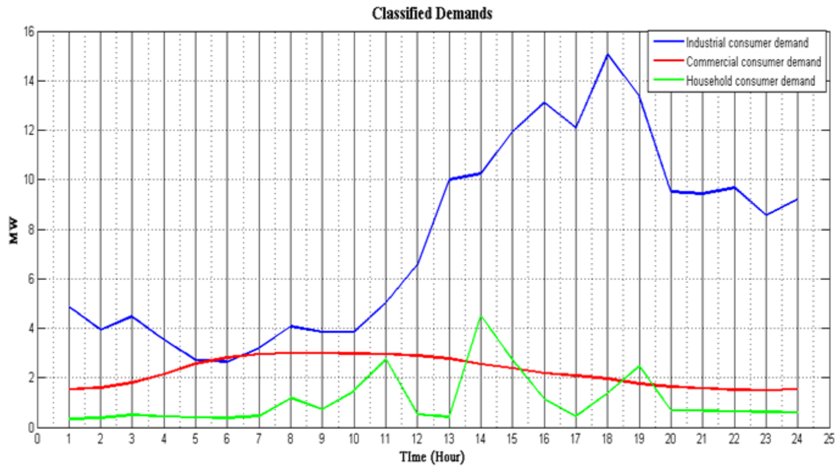
Case Study

Market Simulation Parameters

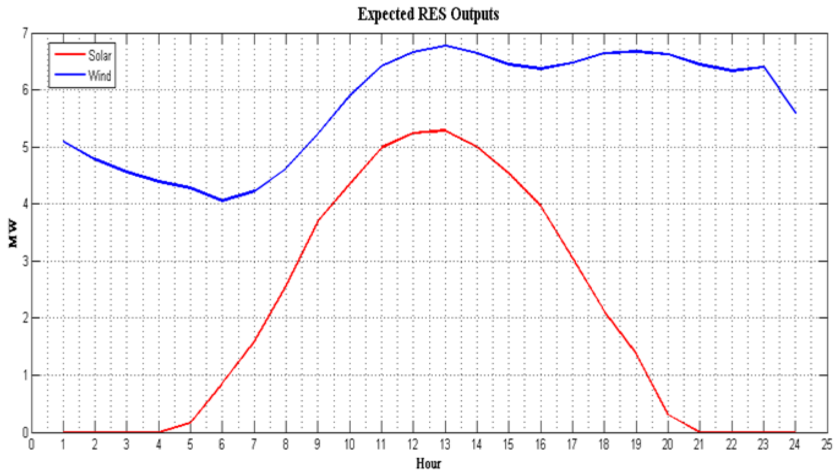
- Expected Load
- Expected Generation
- Expected Market Prices
- Price elasticity

Energy resource type	Size (MW)
Wind	6
Solar	6
Conventional Generator	6
Peak Demand	16
Minimum Acceptable Reduction	0.3

Expected Loads

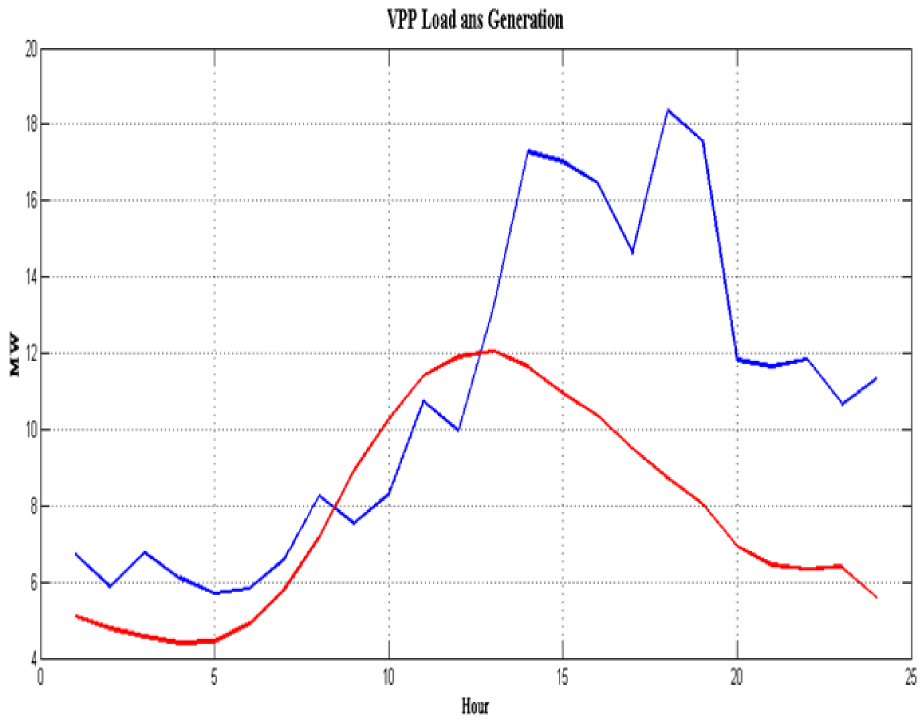


Expected Generation

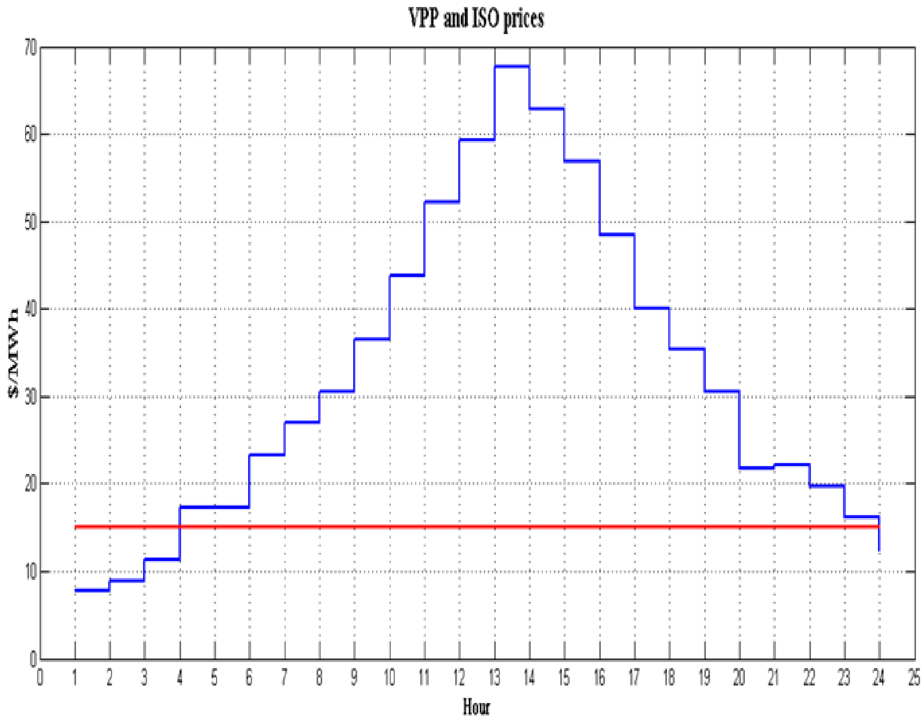


Market Simulation Parameters

Total Load and Generation



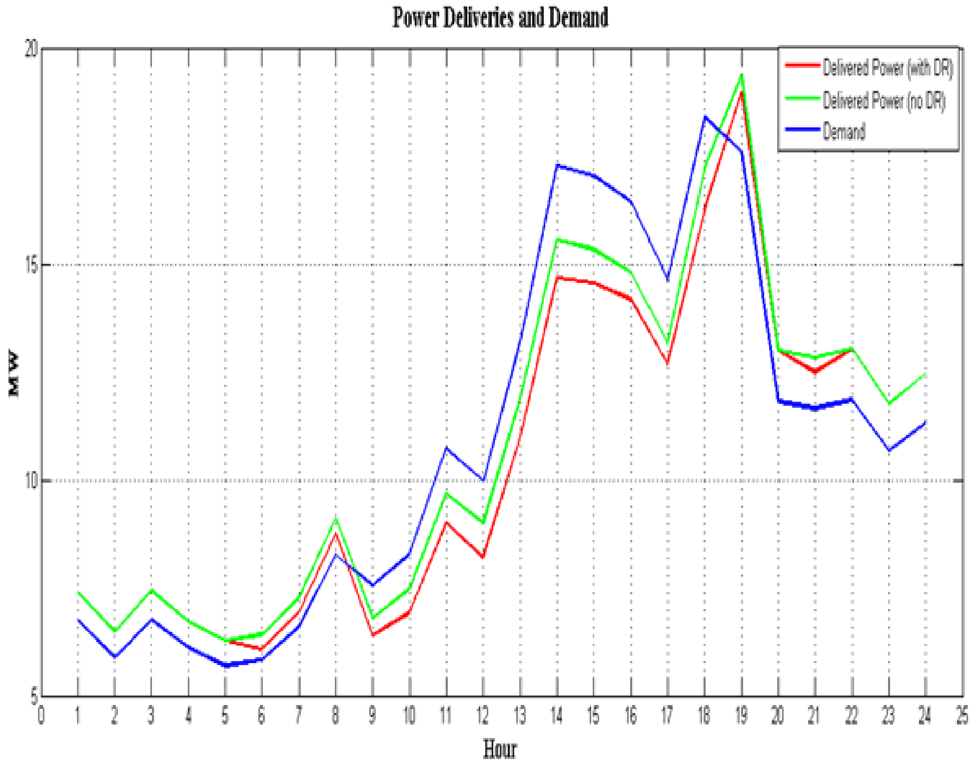
Market Prices



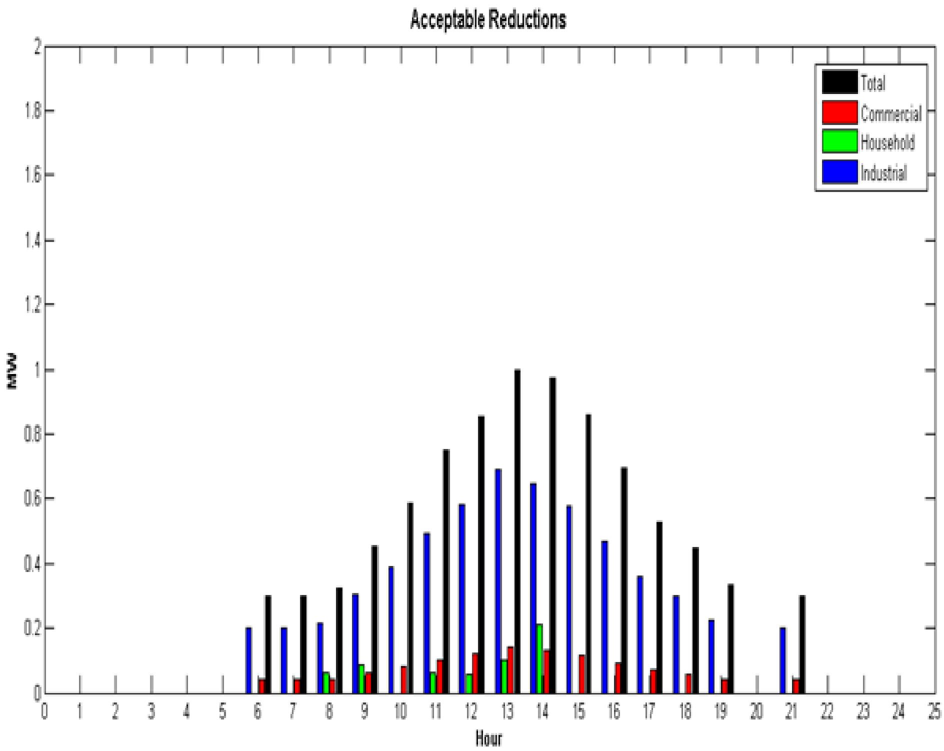
Results

Market Simulation Results

Internal energy delivery

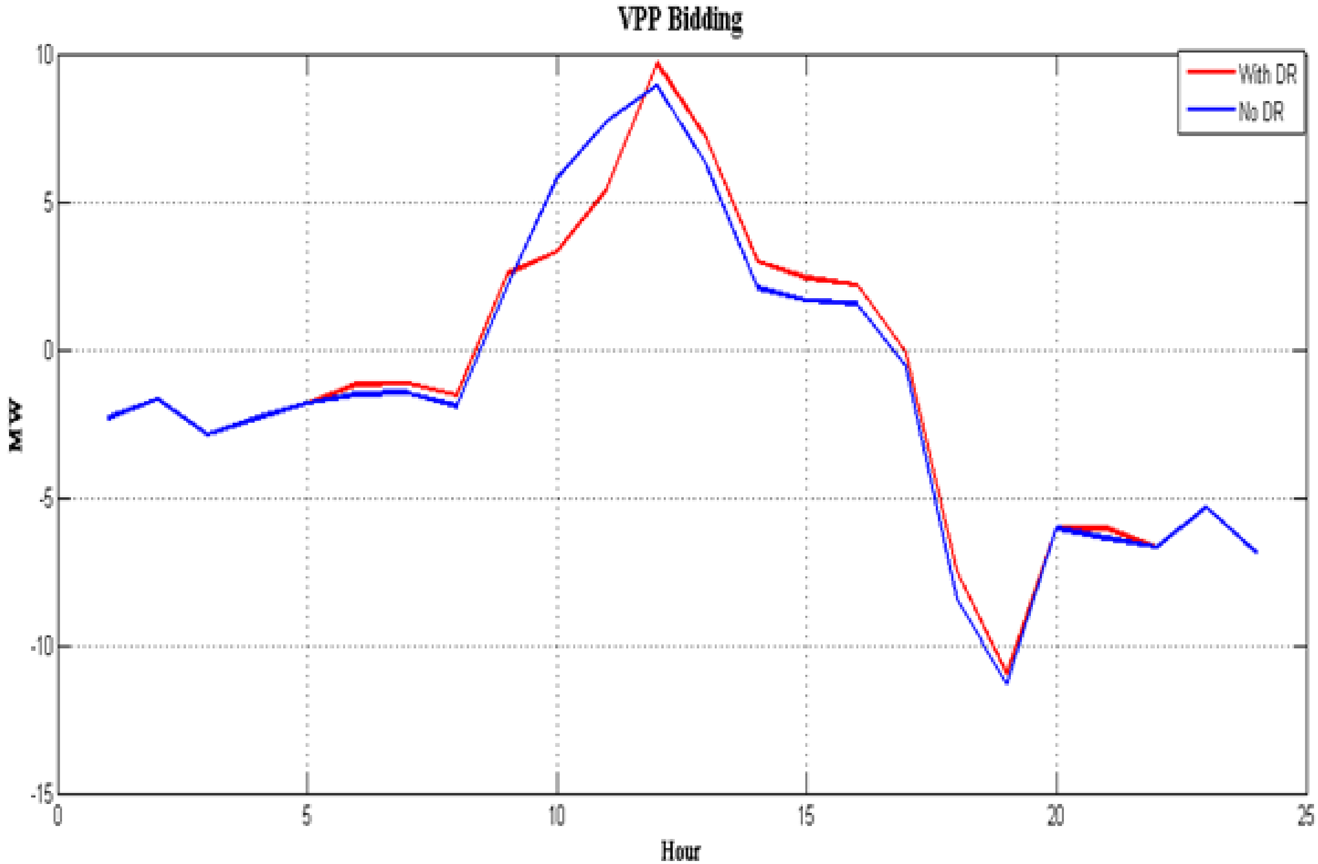


Reductions



Market Simulation Results

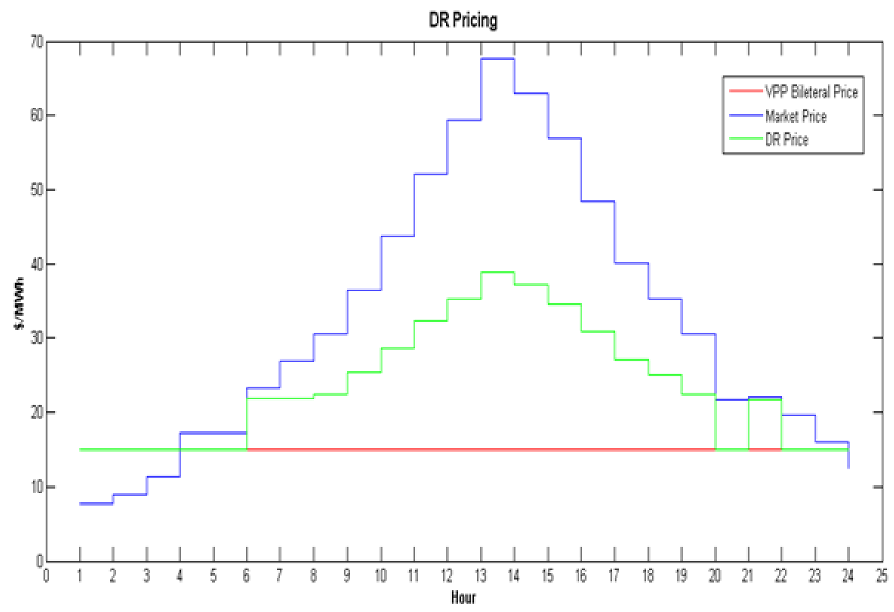
VPP Bidding Into External Market



Market Simulation Results

DR Status	VPP Profit ($)	Dispatchable generator operation (Hours)
Enabled	2049.342	7
Disabled	1700	8

DR Pricing



Conclusions

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- Coupled aggregation coordination of generation and loads
- Optimal energy and DR pricing mechanisms
- New bi-level market structures for VPPs enabling active participation of demand side in energy trades
- Important DR features and benefits in the context of VPPs

Future Work

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- Integration of large scale electrical vehicle (EV) infrastructure
  - ➢ Energy management of aggregated EV portfolio
  - ➢ Energy trades and demand response via charging stations

- Application of short-term demand and generation forecasting methods
- More detailed modeling of decision-making processes in a dynamic environment:
  - ➢ Consumer responsiveness
  - ➢ DR pricing

Questions

THANK YOU