Resource Adequacy and Reliability Impact of Demand Response in a Smart Grid Environment

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Demand Response as A Resource

- Demand response is a new resource that provides new opportunities especially with communication capability in a smart grid environment. It is a price based or an incentive based program.
- Depending on the market design and operational standards, it can offer energy, reserve ancillary services, and capacity.

**Benefits**
- Bill saving
- Reduced Price Volatility
- Reduced Market Power
- Deferred Investments
- Increase short term capacity
- Improve reliability

**Costs**
- Technology Enabling
- Metering and Communications
- Billing System
- Consumer Education
- Administering and Evaluation
- Consumer Inconveniences
Demand Response (DR) for Resource Adequacy

- Resource adequacy is paramount to ensuring reliable, secure, and affordable electric market operations and even low levels of demand response can help to improve resource adequacy and the efficiency of market operations.

- Current resource planning methods often fail to characterize demand response resources properly.

- Probably because of problems such as consumer inertia and unpredictability of response that makes demand response risky.

- The smart grid environment improves probabilistic predictability of system behaviour in presence of demand response.

- Also, the smart grid environment provide the opportunity to obtain different demand response services from different customers and loads.
Demand Response (DR) for Reliability

- For example, some loads are inflexible for energy and capacity but might be suitable for spinning reserve and regulation.

- In some places, spinning reserve is needed exactly when loads such as air conditioners are available.

- The price of spinning reserve is much higher than non-spinning and replacement reserves.

- It can be expected that the combination of high price and short duration of response creates incentive for reliability based demand response.
Our Model of Reliability Based DR in the Smart Grid Environment

- We assume four types of loads: 1) **optional load** (light dimming) 2) **deferrable loads** (dish washer) 3) **controllable load** (water heater) and 4) **storage device load** (electric vehicle).
- The system consists of three parts, consumer, data management centre and system operator that interact with each other.
Our Model of Reliability Based DR in the Smart Grid Environment

- The signal is indicator of following system reliability conditions:
  - **Normal Reliability:** The energy management system (EMS) optimises the consumption profile of the consumer to minimize the energy cost but not necessarily energy consumption. For example it uses the opportunity of deferral loads and storage devices when prices are high. This helps preventing high peaks and release extra resource.

  - **Emergency Reliability:** The EMS minimises both cost and energy consumption for a short period. This will be done, for instance, by dimming light (optional load) or changing thermostat (controllable load). This provides regulation service and avoid high cost which is particularly helpful when penetration of intermittent generation is high.

- The system will be balanced based on a combination of generation reserves and demand response resources in a cost effective way.
Decision Algorithm

We use Markov Decision Process (MDP) Which provide a broad framework for modelling sequential decision making under uncertainty. An MDP consists of four elements:

- $S$ is finite set of states which in our model is 48 (half an hour periods).

- $A$ is finite set of actions - based on the price signal a consumer can increase, decrease or does not change its consumption.

- $P_a(s, s') = \Pr(s_{t+1} = s'|s_t = s, a_t = a)$ is the probability that action $a$ in state $s$ at time $t$ will lead to state $s'$ at time $t + 1$.

- $R_a(s, s')$ is the expected immediate reward received after transition to state $s'$ from state $s$ with transition probability $P_a(s, s')$. 
The goal is to choose a policy $\pi$ that will maximize the expected discounted of rewards:

$$\sum_{t=0}^{\infty} \gamma^t R_{a_t}(s_t, s_{t+1})$$

Where $a_t = \pi(s_t)$ and $\gamma$ is the discount factor that $0 \leq \gamma \leq 1$.

One algorithm to optimise above is to use Bellman (1957) value iteration that is iterated for all states until it converges with the left-hand side equal to the right-hand side.

$$V(s) = \max \left\{ \sum_{s'} P_a(s, s')(R_a(s, s') + \gamma V(s')) \right\}$$
The transition matrix is a tensor of order $48 \times 48 \times 3$ which initially assumed to have a uniform distribution and then it is updated with new information coming from consumer reaction.

The reward functions are assumed to be as follows:

$$R_i = k_{a=i} \times p_{\text{mean}}q_{\text{mean}} - P(t)q(t)$$

$$R_d = p(t)q(t) - k_{a=d} \times p_{\text{mean}}q_{\text{mean}}$$

Where $p$ is price and $q$ is demand and $k$ is a constant that is set based on the action chosen. For the case of $a=$unchanged:

$$R_u = \frac{1}{2} (R_i + R_d)$$
• Under the normal reliability condition the optimal policy for the consumer is to avoid high peak (Upper figure).

• The energy consumed will not change but cost of energy declines.

• Because of consumer inertia and duration of response the reward will not motivate all consumers for load shift and peak avoidance (Lower figure).
Due to shorter duration of emergency reliability responses, the optimal policy for more inertial customers is to respond to reliability and regulating service signals.

Simulation Results - Emergency Reliability

- Load Profile in Emergency Reliability
- Normal Price Signal
- Emergency Reliability Price Signal
Conclusions

- The smart grid environment facilitates the participation of consumers in demand response program.
- Under the condition of normal reliability, the optimal policy is to avoid high peak.
- Peak reduction and load shift is not appealing to all consumers due to long duration of response and associated inconvenience.
- The optimal policy for inertial consumers is to participate in ancillary service provision.
- The smart grid can promote ancillary service demand response from less responsive consumers which itself eases penetration of intermittent generation.
Thanks for Your Attention

Questions?