10. \textit{EV} Integration into Today’s Grids

George Gross
Department of Electrical and Computer Engineering
University of Illinois at Urbana–Champaign
TWENTY-FOUR HOUR PROFILE

MW

Source: California ISO data for 08/08/13
WEEKLY LOAD CYCLE

Source: California ISO data from 08/05/13 to 08/11/13
THE WEEKLY LOAD SHAPE

**Total Available**

**Reserves Margin**

**Base Load**

**Peak**

**Intermediate**

**Load**

**Mon**  **Tue**  **Wed**  **Thu**  **Fri**  **Sat**  **Sun**
CALIFORNIA SUMMER LOAD: TYPICAL DAILY LOAD SHAPE

Source: California ISO data for 07/20/21

peak period
US ENERGY CONSUMPTION IN 2020

Percent of source:
- Petroleum: 32.2 (35%)
- Natural gas: 31.5 (34%)
- Coal: 9.2 (10%)
- Renewable: 11.6 (12%)
- Nuclear: 8.2 (9%)

Percent of sector:
- Transportation: 24.3 (35%)
- Industrial: 25.2 (36%)
- Residential: 11.5 (17%)
- Commercial: 8.7 (12%)
- Electrical system energy losses: 23.2 (65%)

Total consumption: 92.9 quads
Total electricity retail sales: 12.5 quads
Total 35.7 quads

Source: EIA, U.S. Energy Facts Explained, April 2020
2020 US GENERATION BY SOURCE

Total generation = 4,009 TWh

- coal 19.3%
- natural gas 40.3%
- nuclear 19.7%
- hydro 7.3%
- other renewable sources 12.5%
- petroleum/other gases 0.4%

2020 NET GENERATION OF RENEWABLE ENERGY SOURCES

total renewable generation = 792 TWh

- wind 44.0%
- hydroelectric 37.6%
- solar 11.8%
- wood/biomass 4.8%
- geothermal 2.2%

AMEREN ILLINOIS ENERGY SOURCES OF ELECTRICITY SUPPLIED IN 2020

- **Coal**: 34%
- **Wind**: 12%
- **Nuclear**: 17%
- **Natural Gas**: 33%
- **Oil**: 2%

Source: Ameren IP, data for the 12 months ending April 2021; available at https://www.ameren.com/media/illinois-site/files/electricchoice/sourcesofsupply/aic_32850_environmentaldisclosurestatement_0421.pdf?la=en-us-il&hash=5D3D5BEF9E13BCCD23785A1E35095D1
THE ELECTRIC POWER GRID

CHARGING THE EVs

Source: Lucy Sanna, “Driving the solution, the plug-in hybrid vehicle,” EPRI journal, Fall 2005

California load without EVs

load with 4 million PHEVs
THE ELECTRICITY GRID

- The $MWh$ costs and prices are unequal over time
- The value of each $MWh$ depends on the time of production/consumption
- The integration of $EV$s into the grid can fully exploit the opportunities to:
  - buy electricity when the prices are low
  - sell services when the prices are high
  - provide additional services needed by the grid
LOAD AND LMP

Source: NE ISO
LOAD AND LMP

Source: NE ISO
LOAD AND LMP

Source: NE ISO
THE EV AS A "PURE LOAD"

s.o.c. (%)

100

60

6
8
18
24

time of day

6
8

18
24

THE EV AS A "PURE LOAD"
LEVELING THE LOAD

Source: NE ISO
LEVELING THE LOAD

impacts of the controlled charging of the EVs
REGULATION SERVICE AND PRICING

Source: PJM
REGULATION SERVICE AND PRICING

Source: PJM

price ($/MW/h)

demand for regulation (MW)

time of day

Source: PJM
REGULATION SERVICE AND PRICING

Source: PJM
A basic objective of the system operator is to ensure that the supply – demand equilibrium is maintained around the clock.

Imbalances lead to frequency fluctuations that need to be regulated.

In actual systems operations, the supply–demand imbalance is checked every 2 to 4 s.
ROLE OF *EVs* IN FREQUENCY REGULATION

![Diagram showing the role of EVs in frequency regulation.](image)
ROLE OF *EV* _s IN FREQUENCY REGULATION
OFF – PEAK REGULATION

- Compliance with the unit commitment schedules becomes a challenge during the low–load conditions that characterize the off–peak periods.

- While the operator may not wish to turn off any units, there may be no choice.

- Wind integration further exacerbates the low load conditions.

- The regulation prices are typically the highest, as many units are required to reduce their outputs.
PEAK AND OFF – PEAK REGULATION

Source: CAISO

number of days with prices > 250 $/MW/h

time of day

regulation up
regulation down

Source: CAISO
Batteries are able to both absorb and discharge energy

The regulation capacity provided by a battery is relatively small

Batteries provide very short response times (on the order of ms)

The frequent battery charge–discharge switching may, however, may severely reduce battery life
THE EV AS A “SUPPLY-SIDE RESOURCE”

s.o.c. (%)

60

100

time of day

6 8 18 24
BATTERY ISSUES

- The battery capability in terms of $kWh$ storage of an EV is small.
- This capability limitation consequently restricts the “supply–side resource” capacity of each EV.
- A key requirement for grid integration is the aggregation of EVs into a collection with the ability to palpably impact the grid.
THE ROLE OF AGGREGATION

❑ The storage capability $C$ for a typical $EV$ is in the $30 - 60$ kWh range.

❑ If we consider the total discharge of the full battery over $5 \, h$, the output is in the $6 - 12$ kW range.

❑ The aggregator, who gathers together "many" $EV$s to create a nontrivial aggregated output and load, can play a critically important role in the effective integration of $EV$s into the grid so as to beneficially impact both supply and demand–side issues.
V2G FRAMEWORK

- Load aggregation
- Resource aggregation
- Explicit representation of uncertainty
- Communications/control layer construction
- Development of incentives for aggregation
PRINCIPAL PLAYERS IN THE V2G INTEGRATION

- Aggregator
- Aggregated EVs
- ISO/RTO
- ESP
- Local distribution company
THE INTEGRATION FRAMEWORK

Aggregator

load aggregation

resource aggregation

ESP

ISO/RTO
V2G PLAYER INTERACTIONS

- **ISO/RTO**
- **individual EV owner**
- **ESP**
- **aggregated EVs as a resource**
- **aggregated EVs as a load**
- **dollar flows**
- **capacity/energy flows**

**Battery supplier**

- **Parking facility**
FLOWS IN THE V2G FRAMEWORK
REPRESENTATION OF SOURCES OF UNCERTAINTY

- We take into account various sources of uncertainty, including:
  - time of arrival
  - parking time
  - state of charge (s.o.c.)
  - storage capability of the EV battery
  - demand

- For the aggregated EVs, we make explicit use of the Central Limit Theorem (\(N > 30\)) and represent the uncertainty by using approximations based on normally distributed random variables.
Average commute distance is 22 miles = 35 km

Source: Lucy Sanna, “Driving the solution, the plug-in hybrid vehicle,” EPRI journal, Fall 2005
PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY

time of day

fraction of capacity utilized

day 1
PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY

fraction of capacity utilized

time of day

day 1

day 2
PARKING LOT UTILIZATION AS A FRACTION OF ITS CAPACITY

fraction of capacity utilized

time of day

day 1

day 2

day 3

day 4
APPROXIMATION OF PARKING CAPACITY UTILIZATION

fraction of capacity utilized vs. time of day

normal approximation
GAUSSIAN MODEL OF PARKING CAPACITY UTILIZATION

fraction of capacity utilized

normal approximation

time of day

6 8 10 12 14 16 18 20

0 0.2 0.4 0.6 0.8 1
The role of the s.o.c. is critical in the effective management of the aggregated EV integration into the grid. The utilization of a battery depends on its storage capability.
**EVs PROVIDE IMPORTANT SERVICES**

- The **aggregated EVs** constitute a very important supply–side resource to the grid.
- The **EVs** can provide considerable **flexibility** to the **ISO/RTO** in the scheduling of units.
- As a result, the **start-up of cycling and peaking units** may be delayed or avoided; the provision of reserves is strengthened, and reduced reserves are required during off–peak periods.
CYCLING UNITS WITHOUT V2G

Source: NE ISO

MW
0 2 4 6 8 10 12 14 16 18 20 22 24
11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000 19,000 20,000

time of day
load
reserves
peaking units
start-up the cycling units
cycling units

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CYCLING UNITS WITH V2G

Source: NE ISO

The EV batteries contribute to the reserves not supplied by cycling units. Peaking units start-up the cycling units with delay.

Load and cycling units are shown with time of day on the x-axis and MW on the y-axis.
REGULATION SERVICE AND PRICING

Source: PJM
DAY – TIME REGULATION SERVICE PROVISION BY 100,000 EVs
PERCENTAGE OF EVs PROVIDING THE REGULATION SERVICE

The graph shows the percentage of smart vehicles (BV) providing the regulation service over time of day. The percentage remains relatively stable with minor fluctuations throughout the day.
The number of EVs providing regulation service remains rather low, with fewer than 8% of the EVs in the aggregation providing service at any point in time from 8 a.m. to 6 p.m.

We consider the provision of load shaving service in addition to the regulation service.

We show that the Aggregator can also provide 100 MWh of load shaving service at a constant power output between 9:00 and 9:30 a.m. via a collection of 100,000 EVs.
PERCENTAGE OF EVs PROVIDING LOAD SHAVING AND REGULATION SERVICE
ENERGY PROVIDED IN ADDITION TO THE REGULATION SERVICE

The graph shows the maximum constant power output for the 9-9:30 period in addition to the provision of 30-MW regulation service (MW) as a function of the size of BV aggregation in thousands. The y-axis represents power output in MW, while the x-axis represents the size of BV aggregation in thousands.
REGULATION DEMAND FOR OFF-PEAK CONDITIONS

demand for regulation (MW)

- 1000
- 500
0
500
1000

- 1000
- 500
0    
500  
1000

time of day

1 2 3 4 5 6

0 1 2 3 4 5 6

demand for regulation (MW)

REGULATION DEMAND FOR OFF-PEAK CONDITIONS
REGULATION DEMAND FOR OFF-PEAK CONDITIONS

Net demand for regulation (MW)

- 1000
- 500
0
500
1000
10,000 EVs

Time of day

10,000 EVs
REGULATION DEMAND FOR OFF-PEAK CONDITIONS

net demand for regulation (MW)

- 1000
- 500
0
500
1000

10,000 EVs

50,000 EVs

time of day
REGULATION DEMAND FOR OFF-PEAK CONDITIONS

net demand for regulation (MW)

- net demand for regulation (MW)

- 1000
- 500
0
500
1000

- 1000
- 500
0
500
1000

10,000 EVs

100,000 EVs

50,000 EVs

time of day

1
2
3
4
5
6

10,000 EVs

100,000 EVs

50,000 EVs

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REGULATION DEMAND FOR OFF-PEAK CONDITIONS

net demand for regulation (MW)

-1000
-500
0
500
1000

time of day

0 1 2 3 4 5 6

-1000
-500
0
500
1000

10,000 EVs
100,000 EVs

50,000 EVs
500,000 EVs
V2G COMMUNICATION AND METERING

Aggregator

ISO/RTO

ESP

charging station

distribution grid

distribution grid charging station ZigBee transceiver Aggregator
ESSENTIAL COMMUNICATION/CONTROL SYSTEM REQUIREMENTS

- **Speed**: signals need to be sent every 1 to 2 s
- **Range**: every $BV$ in a parking lot must be on the communication network
- **Measurement**: metering must be installed to enable payment for services
- **Reliability**: full utilization of all parked aggregated $BV$s
- **Security**: $BV$s make the network vulnerable to cyber attacks
ESSENTIAL COMMUNICATION/CONTROL SYSTEM REQUIREMENTS

- **Costs:** each BV has an implanted device and the costs per unit must be low for the large collection of aggregated BVs
- **Extendibility:** the communication layer must allow the integration of additional BVs
- **Interoperability:** a non-restrictive, flexible standard needs to be introduced and implemented
INFORMATION LAYER FLOWS

- ID of each $EV$
- Preferences/constraints of each $EV$
- Parking status of each $EV$
- Storage capability of the $EV$ battery
- The $EV$ battery $s.o.c.$
- Power flows from $EV$ battery to the grid
- Measured value of metered quantities
THE ROLES OF THE AGGREGATOR

- Development of the parking infrastructure

- Maintenance of the batteries and the network

- Creation of relationships with the EV and battery manufacturers

- Interface with ISO/RTO
VALUE ADDED BY THE AGGREGATOR

- Provides a “package deal” to the aggregated BVs in terms of:
  - parking facilities
  - service acquisition and provision
  - charging of BVs
  - battery service

- Allows “one-stop shopping” for potential BV participants

- Acts as the “representative” for the provision of environmental benefits from reduced emissions
REFERENCES


OUTLINE

- Supply – side resources
- Demand – side resources
- Impacts of demand – side management (DSM)
- Challenges in DSM implementation
- Illustrative example of savings in DSM
- Role of demand response resources (DRRs)
- DRR participation in electricity markets
MISO CHRONOLOGICAL LOAD FOR THE JULY 15–21, 2013 WEEK

Source: https://www.misoenergy.org/Library/MarketReports/Pages/MarketReports.aspx
MISO CHRONOLOGICAL LOAD FOR THE JANUARY 7–13, 2013 WEEK

Source: https://www.misoenergy.org/Library/MarketReports/Pages/MarketReports.aspx
52 – WEEK DAILY PJM PEAK LOAD PROFILE FOR 2012

SUPPLY – SIDE RESOURCES

- We consider generation sources to be supply–side resources as they provide the grid with:
  - energy; and
  - capacity

- In addition, supply–side resources provide a variety of services ranging from reactive power support to system stability enhancement.

- Unfortunately, many supply–side resources may also have undesirable environmental attributes.
# CONVENTIONAL SUPPLY – SIDE RESOURCES

<table>
<thead>
<tr>
<th>resource use</th>
<th>examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>base–loaded generation</td>
<td>combined cycle, co–generation, coal, run–of–river hydro, geothermal</td>
</tr>
<tr>
<td>mid–range generation</td>
<td>combined cycle</td>
</tr>
<tr>
<td>peaking generation</td>
<td>gas turbine, peaking hydro</td>
</tr>
<tr>
<td>purchases from other entities</td>
<td>firm capacity and energy contracts</td>
</tr>
</tbody>
</table>
## ADDITIONAL SUPPLY – SIDE RESOURCES

<table>
<thead>
<tr>
<th>resource type</th>
<th>examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>non–utility source purchases</td>
<td>co–generation; wind, small hydro, small coal, solar; larger thermal resources</td>
</tr>
<tr>
<td>exchanges</td>
<td>peaking capacity with off–peak energy return; seasonal capacity exchanges</td>
</tr>
<tr>
<td>renewable</td>
<td>solar, wind, hydro, PV, biomass</td>
</tr>
<tr>
<td>energy storage</td>
<td>pumped storage hydro, compressed air energy storage technology, batteries</td>
</tr>
</tbody>
</table>
DEMAND – SIDE RESOURCES

- Programs designed to modify the demand via:
  - efficiency improvement/energy conservation;
  - electricity consumption reduction; and/or
  - shift of loads to periods with lower demand to help to effectively meet customers’ demand, but with a reduced negative environmental impact.

- We call these programs demand–side management (DSM) or demand–side resources (DSRs).
DEMAND – SIDE RESOURCES

- Conceptually, we may view DSM as a “source” of energy for meeting the system demand.

- Conservation measures save energy since they put a stop to certain types of consumption; for example, insulation of a house reduces heating/air conditioning needs over the life of the house.

- Every implemented energy conservation effort reduces overall demand in all subsequent periods.
Efficiency improvements serve to reduce demand without necessarily removing the load: e.g., Energy Star appliance purchases to replace the earlier, conventional appliances create benefits via the reduced energy consumption and lower expenses and, moreover, the reductions in emissions.

An efficiency measure reduces the need to add generation, but complications do arise.
ENERGY EFFICIENCY IMPLICATIONS

- The implementation of technology that improves the efficiency of a process implies that we can obtain the same output as with the pre-efficiency improvement process, but the new process uses less energy input with reductions in emissions.

- Unfortunately, the energy efficiency improvement in a specific application reduces the required energy input but need not significantly reduce the total energy consumption for that application.
ENERGY EFFICIENCY IMPLICATIONS

- For example, we consider the case of doubled number of km per l of input fuel, say from 8 km/l to 16 km/l; typically, such an efficiency increase results in the use of the cars to go twice as far as before and thus results in zero reduction in the total fuel consumed; ditto for the associated emissions.
DSRs

- Demand shifting programs aim to move energy consumption from peak load times to periods of lower system loads, typically, in off-peak hours; such load shifts serve to reduce or defer the need for additional capacity from supply resources.

- Load management programs are able to switch loads on and off to effectuate lower system demand at various times, particularly at times of peak load, in order to reduce reliance on peakers.
DEMAND-SIDE MANAGEMENT

- The term demand-side management (DSM) was used in the earlier, regulated environment to refer to the implementation of extensive programs that modify the demand of the system.

- In practical terms, a DSM program is any measure that impacts load on the customer side of the meter.

- In analogy to supply-side resources, DSRs may be targeted for base, intermediate and peaking uses to attain economic benefits with a reduction of the impacts on the environment.
DSM PROGRAMS’ LOAD SHAPE OBJECTIVES

- Flexible load shape
- Peak clipping
- Strategic conservation
- Strategic load growth
- Valley filling
- Load shifting
## TYPICAL EXAMPLES OF DSM PROGRAMS

<table>
<thead>
<tr>
<th>Program Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reduction</td>
<td>Conservation</td>
</tr>
<tr>
<td>Load Buildup</td>
<td>Marketing</td>
</tr>
<tr>
<td>Load Shifting</td>
<td>Load Management</td>
</tr>
</tbody>
</table>
ENERGY EFFICIENCY AND ECONOMIC DEVELOPMENT

WE’LL PAY YOU IF WE CAN DO THIS TO YOUR SPARE REFRIGERATOR.

- You’d flatten your spare refrigerator yourself, if you realized how wasteful it is. An average one devours a whopping $150 a year in energy costs. • If you let us recycle it, not only will you get rid of an old energy guzzler; you’ll get a $50 savings bond from Edison or DWP. • To qualify, it must be in working order and used as a second refrigerator for the last six months. • So for your $50 savings bond, call Edison or DWP at 1-800-234-9722. Or use our TDD accessible number 1-800-234-9710. It pays to recycle your spare refrigerator.

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If you compete in the high tech, food, aircraft maintenance or plastics industries, TU Electric can help you make it in Texas. And your timing couldn’t be better. Texas is one of the states people want to move to. We’re ideally located between both coasts, with easy access to national and international markets. We’ve got low cost land. Low cost labor. Low cost rents. But we’re rich in transportation with D/FW Airport and a good freight and highway system. And our utilities, like electric power, are reliable and reasonable.

To get a jump on your competition, get on down here. We have a wealth of statistics, maps and firsthand experience to pass along. Contact John Prickett at 1-800-421-2489. Fax 214/934-5456.

TUELECTRIC
We put a lot of energy into business.
RENEWED INTEREST IN DSM

- After the assessment of DSR-provided services, the Federal Energy Regulatory Commission (FERC) has repeatedly encouraged the incorporation and wider expansion of DSM within today’s organized electricity markets.

- Several grid operators – ISO-NE, NYISO, PJM and ERCOT – have encouraged consumer participation and have taken steps to integrate DSM into their wholesale markets.
RENEWED INTEREST IN DSM

- Some states (MD, NJ, NY and PA) have adopted real–time pricing as a default service for large clients or have implemented critical peak pricing programs (CA, FL)

- Several utilities (Georgia Power, Duke Power, TVA) have attracted significant customer participation in real–time pricing programs as an optional service for large customers
RENEWED INTEREST IN *DSM*

- Many utilities have already deployed or are considering the deployment of advanced metering infrastructure (*AMI*) on a system-wide basis to implement price-sensitive demand response.

- The number of US *AMI* units deployed is about 103 million in 2020 and is growing year by year.
### APPROPRIATE DSM APPLICATIONS FOR DIFFERENT LOAD SEGMENTS

<table>
<thead>
<tr>
<th>intended load segment</th>
<th>base</th>
<th>intermediate</th>
<th>peaking</th>
</tr>
</thead>
<tbody>
<tr>
<td>typical programs</td>
<td>motors</td>
<td>building weatherization</td>
<td>air-conditioner control</td>
</tr>
<tr>
<td></td>
<td>water heater, refrigerator and freezer efficiency improvements</td>
<td>air-conditioner or heat pump efficiency improvements</td>
<td>thermal storage HVAC</td>
</tr>
<tr>
<td></td>
<td>lighting</td>
<td>stricter appliance efficiency standards</td>
<td>high peak rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>time-of-use rates</td>
<td></td>
</tr>
</tbody>
</table>
The key objective is to *strategically* reduce end user consumption at peak load times.

The deployment of these programs avoids the need to construct more peaking units.

Such programs, typically, have *minor impacts* on total energy consumption.
These programs constitute the mature parts of DSM.

The two major classes of programs

- direct load control; and
- indirect control using pricing–based options – interruptible, curtailable, time–of–use rates – or the deployment of specially designed incentives for load management.
BASIC ASPECTS OF \textit{DSM}

- The \textit{DSM} activities focus on the \textit{customer–side of the meter} and aim to influence end use of electricity to obtain the desired \textit{changes in the load shape}.

- \textit{DSM}, in practice, has become a collection of programs for increased efficiency, load management and conservation; programs aim to reduce the need for more electrical energy generation resources and additional installed capacity.
DSM PROGRAMS’ LOAD SHAPE OBJECTIVES

- **flexible load shape**
- **peak clipping**
- **strategic conservation**
- **strategic load growth**
- **valley filling**
- **load shifting**
BASIC ASPECTS OF DSM

- Load demand is not considered to be fixed: the changes in demand are planned concurrently with supply–side modifications, and the DSM program execution and energy dispatch are carried out in an integrated manner.

- The dispatch of implemented DSM programs becomes an inherent part of system operations.
Modification of the chronological load shape

Reduction of the peak load

Delivery of the electricity at a lower consumption level

Reduction in the overall emissions

Deferral and possible avoidance of the need to add new supply–side resources
DSM INTEGRATION

**MW**

- **chronological load without DSM**
- **modified chronological load**

**impact of the time-dependent DSM resource**

**energy reduction due to DSM resource**
KEY CHALLENGES IN DSM IMPLEMENTATION

- Electricity service providers (ESP) need to overcome the disincentives caused by conventional rate-making realities: the more electricity is sold, the higher the contributions to profits.

- The development of rate structures that not only permit the recovery of DSM program costs but also provide additional incentives to encourage DSM implementation over investments in grid-integrated supply-side resources is critically important.
KEY CHALLENGES IN DSM IMPLEMENTATION

- The *education/training of customers* through the timely provision of information on topics, such as:
  - effective energy utilization;
  - the important role of demand in attainment of supply–demand balance; and
  - cost–effective approaches to manage the customer energy needs

is a fundamentally important requirement.
KEY CHALLENGES IN DSM IMPLEMENTATION

- Design and implementation of appropriate tariffs and incentives for customers to
  - improve efficiency and adopt new conservation measures;
  - shift loads to periods with lower demand;
  - obtain regulatory approval for their timely launch and marketing

- Solution to the free rider problem
An energy services company (ESCO) undertakes a lighting program to improve energy efficiency through the replacement of 75–W incandescent bulbs by 18–W, 10,000–h compact fluorescent lamps (CFL) that produce an equivalent amount of illumination.

As an incentive to customers, the ESCO offers a $2 rebate on each installed CFL.
EXAMPLE: SHARED SAVINGS PROGRAM

- We have the following data for the *ESCO* program:

<table>
<thead>
<tr>
<th>parameter</th>
<th>unit</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>marginal costs</td>
<td>¢/kWh</td>
<td>3</td>
</tr>
<tr>
<td>average costs</td>
<td>¢/kWh</td>
<td>2</td>
</tr>
<tr>
<td>number of CFLs installed</td>
<td>–</td>
<td>$10^6$</td>
</tr>
<tr>
<td>administrative/overhead costs</td>
<td>$/CFL</td>
<td>1</td>
</tr>
</tbody>
</table>
EXAMPLE: SHARED SAVINGS PROGRAM

- We compute the energy savings to be
  
  \[ kWh\text{ saved } = (75 - 18)(10,000) \times 10^6 = (570) \times 10^6 kWh \]

  \[ W \quad h \quad CFL\text{ units installed} \quad \text{energy savings per CFL unit} \]

  which correspond to

  \[ \text{energy cost savings } = (57) \times 10^7 (0.03) = \$ 17.1M \]

- The program costs are

  \[ \text{implementation costs } = (2 + 1) \times 10^6 = \$ 3M \]
The net savings for the *ESCO* are

\[ \text{net savings} = 17.1 - 3 = \$14.1\ M \]

A shared savings program is typically carried out with the allocation of the net savings to the customers and the *ESCO* along some specified basis: consider an allocation of 15% to the *ESCO* and 85% to the customers:

\[ \text{*ESCO net benefits} = \$2.12\ M \]
\[ \text{customers net benefits} = \$11.99\ M \]
The ability of the ESCO to directly receive a share of the net savings provides incentives to undertake additional lighting programs.

\[
DSM\ \text{costs/kWh} = \frac{\$3}{570\ \text{kWh}} = \frac{\cent 300}{570\ \text{kWh}} = 0.52\ \cent/\text{kWh}
\]

The CFL program is judged to be cost effective since

\[
\text{average costs} + DSM\ \text{costs} = 2 + 0.52 = 2.52\ \cent/\text{kWh} < 3\ \cent/\text{kWh} = \text{marginal costs}
\]
A SIMPLE COST–EFFECTIVENESS TEST

marginal costs less than average costs
marketing programs make sense

marginal costs greater than average costs
consumption reduction programs make sense

marginal costs = average costs
“cap” on consumption reduction expenditures

average variable costs
fixed costs component of the average costs

per unit costs ($/kWh)
sales (kWh)

average costs
marginal costs

0
DEMAND RESPONSE RESOURCES (DRRs)

- price-sensitive passive loads
- generation resources
- market clearing
- transmission scheduling

DRRs involve generation resources, price-sensitive passive loads, and market clearing and transmission scheduling.
THE NATURE OF DRRs

- The objective of DRRs is to make the load an active participant in the around-the-clock balance of electricity supply and demand via side-by-side competition with supply-side resources.
- DRRs curtail their loads in response to incentive payments to reduce electricity consumption at specified times.
- DRRs are attractive alternatives to supply-side resources to meet the supply-demand balance.
DRR ACTIVITIES

Flexible load shape
Peak clipping
Valley filling
Load shifting

DRRs help to balance the supply and demand around the clock and in ancillary service provision.

Transmission scheduling  Market clearing  Ancillary services
$/MWh

high willingness-to-pay of fixed loads

market equilibrium
Impact of hour $h$ DRR curtailment

Reduction in market clearing price

Impact of hour $h$ DRR curtailment

$\lambda^*$ $\lambda'$ $\Delta \lambda$ $\ell'$ $\ell^*$

$/\text{MWh}$ $\text{MWh}/\text{h}$
**DRRs ARE ATTRACTIVE**

- *Jon Wellinghoff, past Chairman, FERC:* “There are tremendous benefits from demand response at very low costs, costs much lower than we can put any supply in place. This is the first fuel.”

- *Jim Rogers, CEO, Duke Energy:* “The most environmentally responsible plant you build is the one that you don't build.”
DRR IMPLEMENTATION DRIVERS

Environmental concerns

Advent of aggregators

DRR implementation

Reliability

Smart grid technologies

Policy initiatives
DRR LIMITATIONS AND CHALLENGES

- The potential for DRR implementation is limited and challenges arise as DRR penetrations deepen.
- Policies to incentivize DRR participation must be formulated in such a way as to effectively balance the benefits among all the market players – the sellers – suppliers – and the buyers – consumers.
DRR LIMITATIONS AND CHALLENGES

- DRR curtailments in high-load hours are likely to be followed by energy recovery in lower-load hours, the so-called payback effects, with the associated price impacts.

- DRRs cannot provide the system dynamic effects that generators do and so there are physical limitations to the depths of effective DRR penetration.
DRR WITH ENERGY RECOVERY

MWh/h

DRR curtailments

system load

DRR energy recovery
$D_{RR}$ WITH ENERGY RECOVERY ACTS

- **MWh/h**
- **reduced system peak load**
- **increased system base load**
- **$D_{RR}$-modified system load**
FERC ORDER NO. 745

- FERC Order No. 745 specifies the incentives to the DRRs for load curtailments in the DAMs.

- The Order represents a significant increase in DRR incentives over past practices.

- These incentives provide a major stimulus for DRR participation in electricity markets.
DISTRIBUTED ENERGY RESOURCES (DERs)

- We use the term resources to refer to both supply- and demand-side resources.
- We refer to energy resources integrated into the distribution grid as DERs.
- The participation of DERs in electricity markets presents various technical and implementation challenges to RTOs/ISOs, including:
DISTRIBUTED ENERGY RESOURCES (DERs)

- DERs are integrated into a grid, over which the RTOs/ISOs have no monitoring/control capabilities.
- There is a limit of the size of a resource that is palpable to the bulk grid.
- DER operational constraints arise from both the distribution and the transmission grids.
- The presence of numerous DERs may lead to computational & communication challenges.
DER OPPORTUNITIES

- Distribution-side DRRs are also DERs and a large portion of the demand is on the distribution side.
- Residential DRR examples are “smart” appliances, water-heating and HVAC systems.
- DERs also include rooftop PV and EV batteries.
- DERs can provide capacity at times of peak demand to avoid costly infrastructure upgrades.
- DER integration enables retail customers to purchase electricity when demand/prices are low and to provide various services to the grid.
AGGREGATOR SERVICES

Aggregator

- Electricity consumption
- Curtailment and provision
- Capacity
- Ancillary services

Information flows:

- Electricity consumers
- ISO/RTO

$$flows$$
The coordinated operation of multiple DERs enables RTOs/ISOs to represent DERs as a single aggregated resource to simplify DER representation.

The aggregator is the entity that performs such coordination and acts as the liaison between the ISO/RTO and electricity consumers to enable DERs to participate in bulk electricity markets.

In September 17, 2020, FERC issued Order No. 2222 to specify the rules of participation by DER aggregations in bulk electricity markets.
OFFICIAL \textit{DER} DEFINITION

- Order No. 2222 officially defines \textit{DER}s as “any resource located on the \textit{distribution system}, any subsystem thereof or behind a customer meter”

- This broad and technology-independent definition enables, virtually, any device connected to the \textit{distribution grid} to be considered to be a \textit{DER}
FERC ORDER NO. 2222

- Order No. 2222 requires ISOs/RTOs to allow all DERs whose capacity is 100 kW or higher to participate in bulk electricity markets.

- DERs with capacity below 100 kW may still provide services to electricity markets through an aggregator, defined as "the entity that aggregates one or more DERs for purposes of participation in the capacity, energy and/or ancillary service markets of the RTOs and/or ISOs."
ROLE OF AGGREGATION

- An aggregator is officially defined in Order No. 2222 as “the entity that aggregates one or more DERs for purposes of participation in the capacity, energy and/or ancillary service markets of the RTOs and/or ISOs”

- Aggregators act as the intermediary between the ISO/RTO and electricity consumers to deliver services from DERs to markets