SMART GRID Technologies

PE/PE/HT/324C

Professional Elective Course

Smart Grid Technologies

- Automatic Voltage Regulation (AVR)
- Automatic Generation Control (AGC)
- Energy Management System (EMS)
- Distribution Management Systems (DMS)
- **Demand Side Management (DSM)**
- Outage Management System (OMS)
- Wide Area Management System (WAMS)
- Advanced Metering Infrastructure (AMI)
- Meter Data Management (MDM)
- Geographical Information System (GIS)

Demand Side Management (DSM)

Smart grid is a bidirectional electric and communication network which includes various energy and operational devices including smart accessories, smart meters, nonconventional energy resources and energy-storing devices

Smart grid technologies are being enforced in India in order to reduce transmission and distribution losses

Demand side management (DSM) is an important function of a smart grid and it helps to reduce the utilization costs of electricity

It allows energy suppliers to reduce peak load demand

The method involves system state identification and it enables the user to schedule their loads

This potentially balances both supply side and demand side in order to make the system more efficient

Demand Side Management (DSM)

Demand side management (DSM) is one of the crucial aspects of smart grid that provides users with the opportunity to optimize their load usage pattern to fill the gap between energy supply and demand and reduce the peak to average ratio (PAR), thus resulting in energy saving and economic efficiency ultimately

The application of DSM programs is lucrative for both utility and consumers

Utilities can implement DSM programs to improve:

- power quality
- power reliability
- system efficiency
- energy efficiency

while consumers can experience:

- energy savings
- reduction in peak demand
- improvement of system load profile
- maximize usage of renewable energy sources (RESs)

Demand Side Management (DSM)

DSM can be defined as a set of techniques that can be used to modify the consumption pattern of the end users of electricity over time

DSM methods encourage the users to optimize their energy usage and focus on reducing the energy cost and improving the efficiency

DSM not only benefits the consumers by reducing their energy bills, but also benefits the energy systems or utilities through shifting the load from peak to non-peak hours

Energy consumption patterns at consumers' premises vary throughout the day depending on users' activities

The generating capacity must be able to fulfill the energy demand in peak periods

DSM actions are used in smart grid to manage load profile of the end users for efficient utilization of generated power

Demand Side Management (DSM)

Over time, more concern is being paid to the demand side rather than modifying the generating side of the power system to fill the gap between the energy supply and demand

Electricity suppliers can modify the energy consumption pattern on the consumer side through proper implementation of DSM

Demand Side Management (DSM)

The DSM program is made to tackle the peak load demand induced by the residential customers in smart grid with multiple suppliers. It can be modeled as two noncooperative games:

- the supplier side game
- The customer side game

The supplier side game aims to maximize the supplier’s profit

The suppliers send their bids to the DSM center, where energy price is calculated and is sent to the customers

In the second game, the customer aims to determine the optimal load profile to maximize their daily payoff

The two games are played simultaneously, and there exist a unique equilibrium point for both games

Demand Side Management (DSM)

The utility aims to minimize operational cost, DR aggregator aims to maximize net benefit, and consumers aim to minimize their electricity bills

Such a multiobjective problem is formulated to achieve these objectives that are solved using artificial neural network algorithm.

To improve the effectiveness of DSM for all consumers, detailed consumption data of all consumers is required

With the development of “advanced metering infrastructure (AMI),” consumption data of all consumers can be collected by the utilities, and various DSM programs can be developed depending on the data characteristics

DSM

DSM measures are taken by utilities or the end users themselves

Utilities make efforts to persuade consumers to modify their demand patterns by introducing positive tariff incentives

It will permit the users to shift their demand activities at times that will minimize their electricity costs and also help utilities by shifting the demand away from peak periods

The users can either directly reduce their energy consumption or move their demand activities to the periods of low peaks to reduce the bills

DSM

The DSM methods focus on:

- reducing the energy consumption cost
- minimizing the peak demand
- improving the peak to average ratio
- minimizing the user discomfort through modification in operating patterns of the devices
- increasing consumption of energy obtained through local generation sources

Objectives of DSM

The major objectives of demand side management are:

- Electricity cost minimization
- Minimize customer discomfort
- Maximize usage of local energy generation
- Minimize peak demand
- Minimize peak to average ratio

Types of DSM Methods

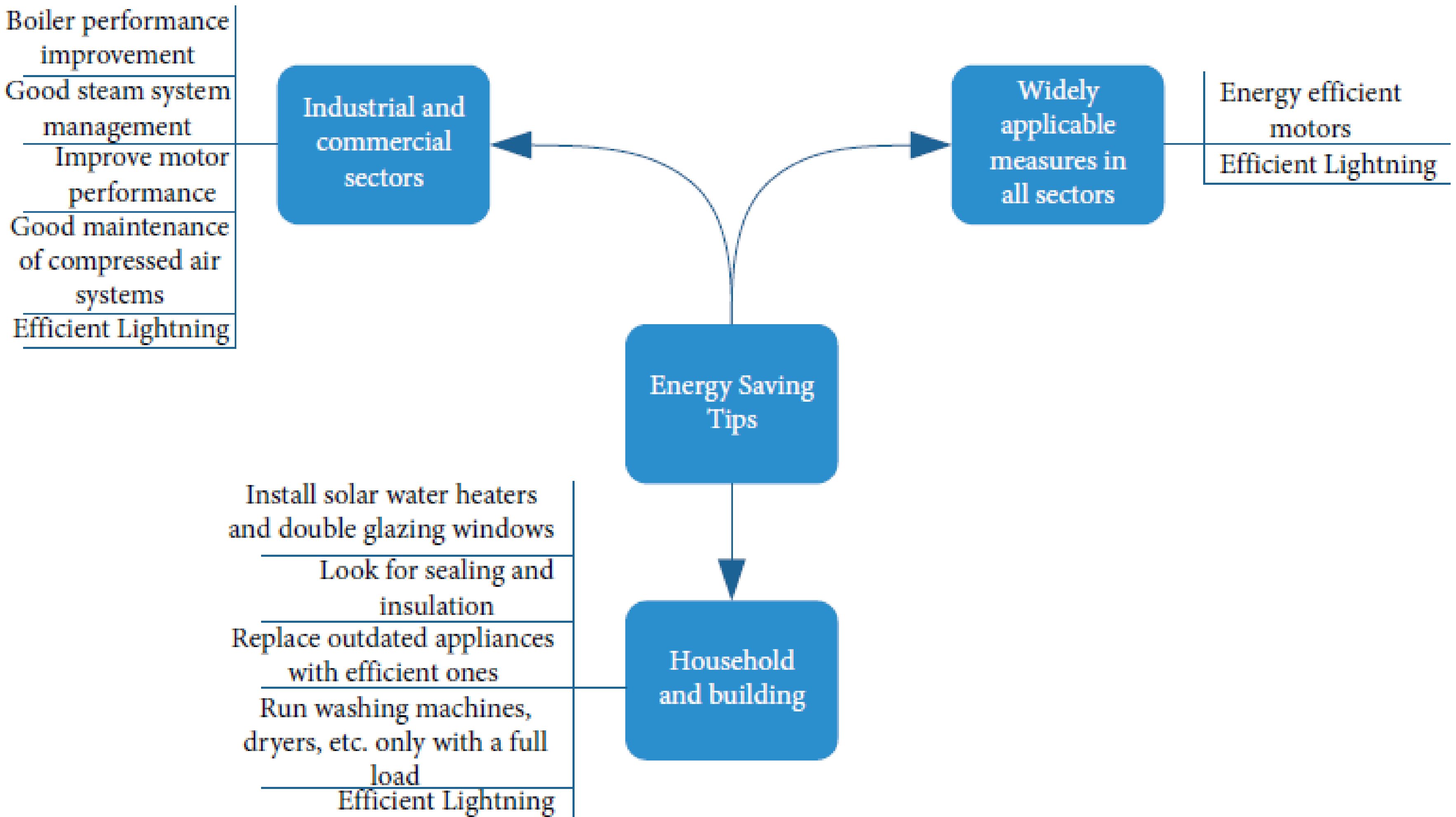
The types of DSM methods can be classified into the following categories:

- Energy reduction methods
- Load management methods

Types of DSM Methods – Energy Reduction

Energy Reduction Methods

- This category covers a wide range of suitable measures that can be adopted to reduce power consumption in all sectors



Types of DSM Methods – Energy Reduction

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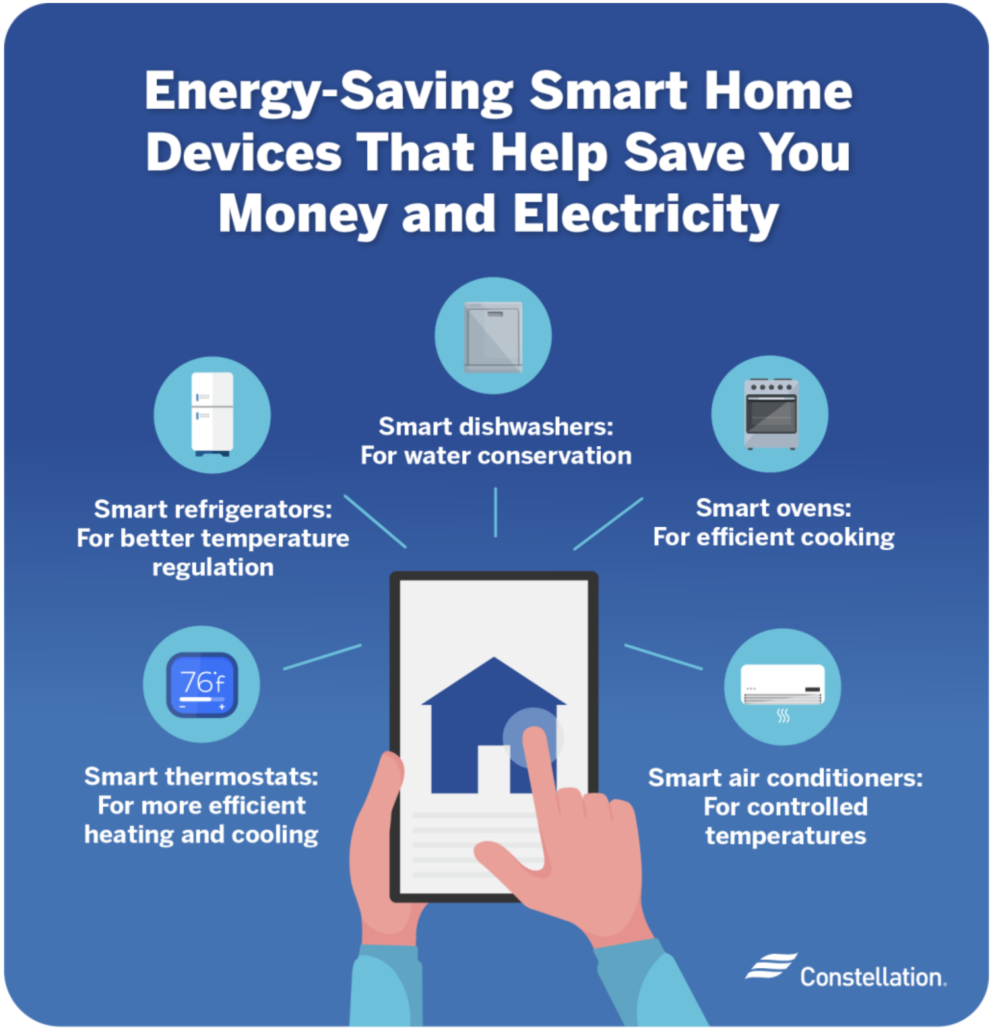


Types of DSM Methods – Energy Reduction

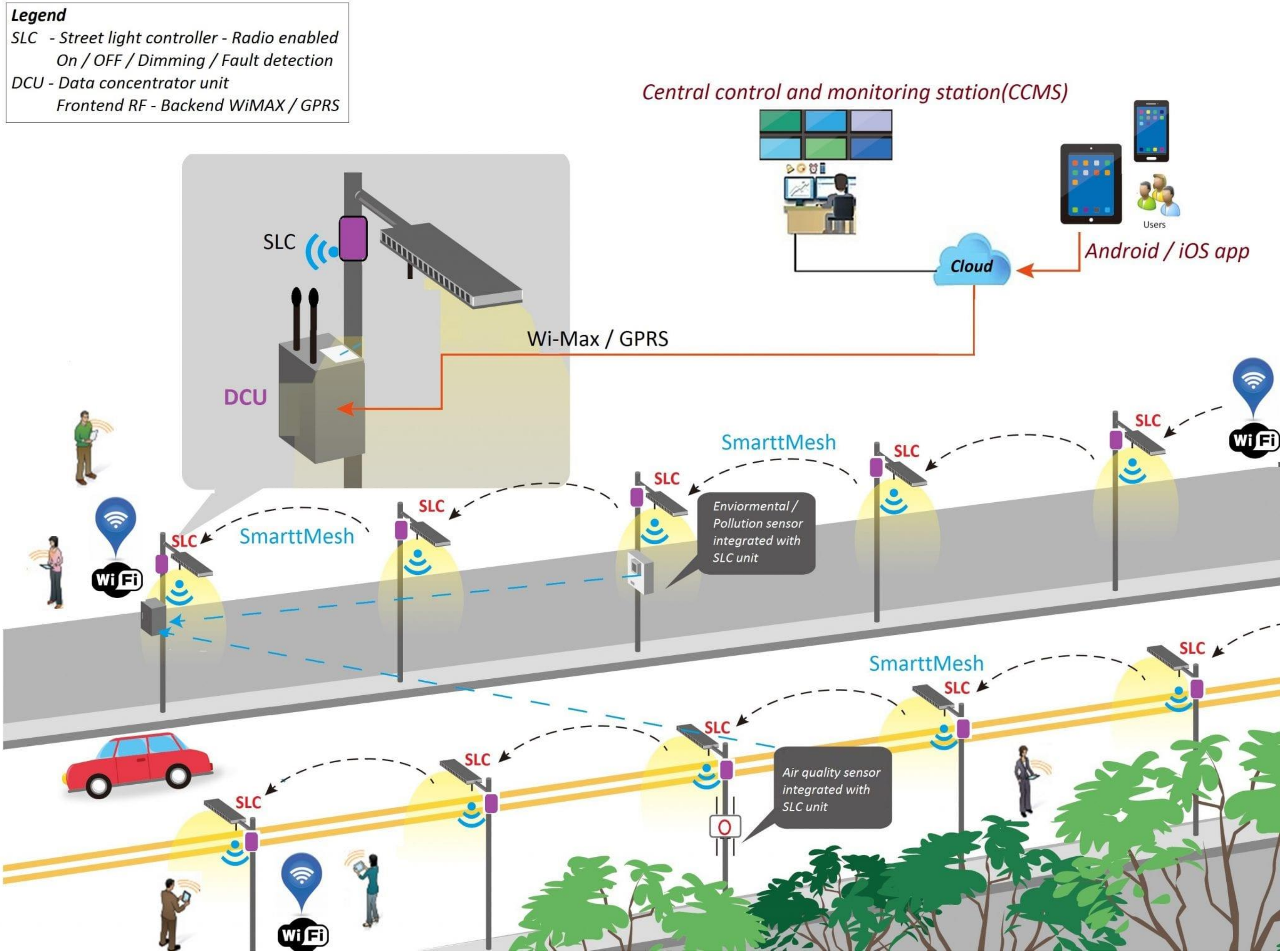
An optimization technique using fuzzy controller and integer linear programming technique can be used to minimize overall power consumption by optimizing nonflexible load without disturbing user comfort

For solving the DSM challenge in home area networks (HANs), an AI approach can be used that updates the system every day based on learning the preference of appliance utilization along with considering the consumer's behavior for avoiding any discomfort

Other DSM application areas

- Building DSM
- Street light DSM
- Parking area DSM
- Shopping center DSM
- Factory DSM

Types of DSM Methods – Energy Reduction



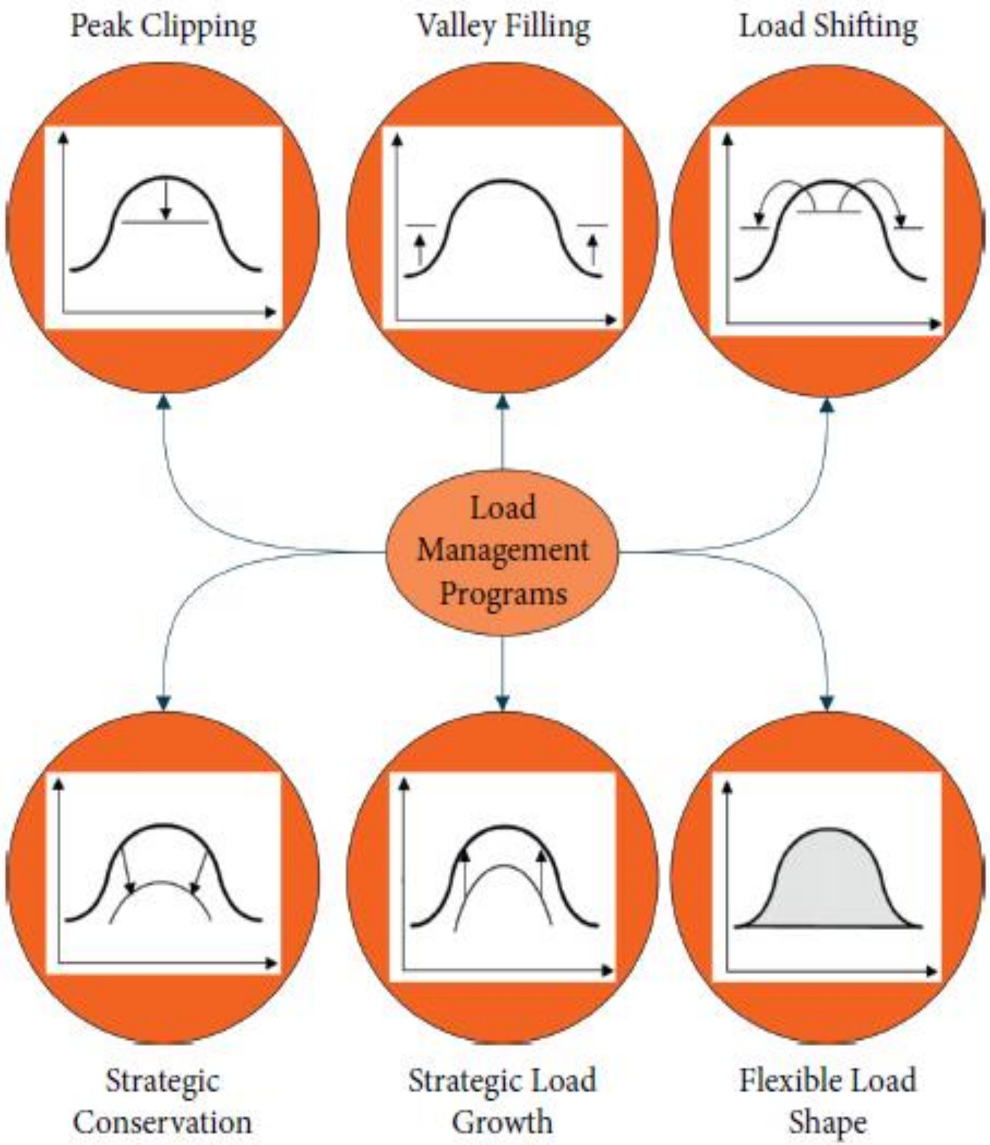
Types of DSM Methods – Load Management

The actions performed to adjust and control the load instead of power supply on a network for achieving the balance between electricity supply and the load are known as load management methods

Electricity cost and load patterns are closely related to each other

Modifications in load pattern can help reduce electricity cost, which is one of the major goals of DSM

Types of DSM Methods – Load Management



Load management programs.

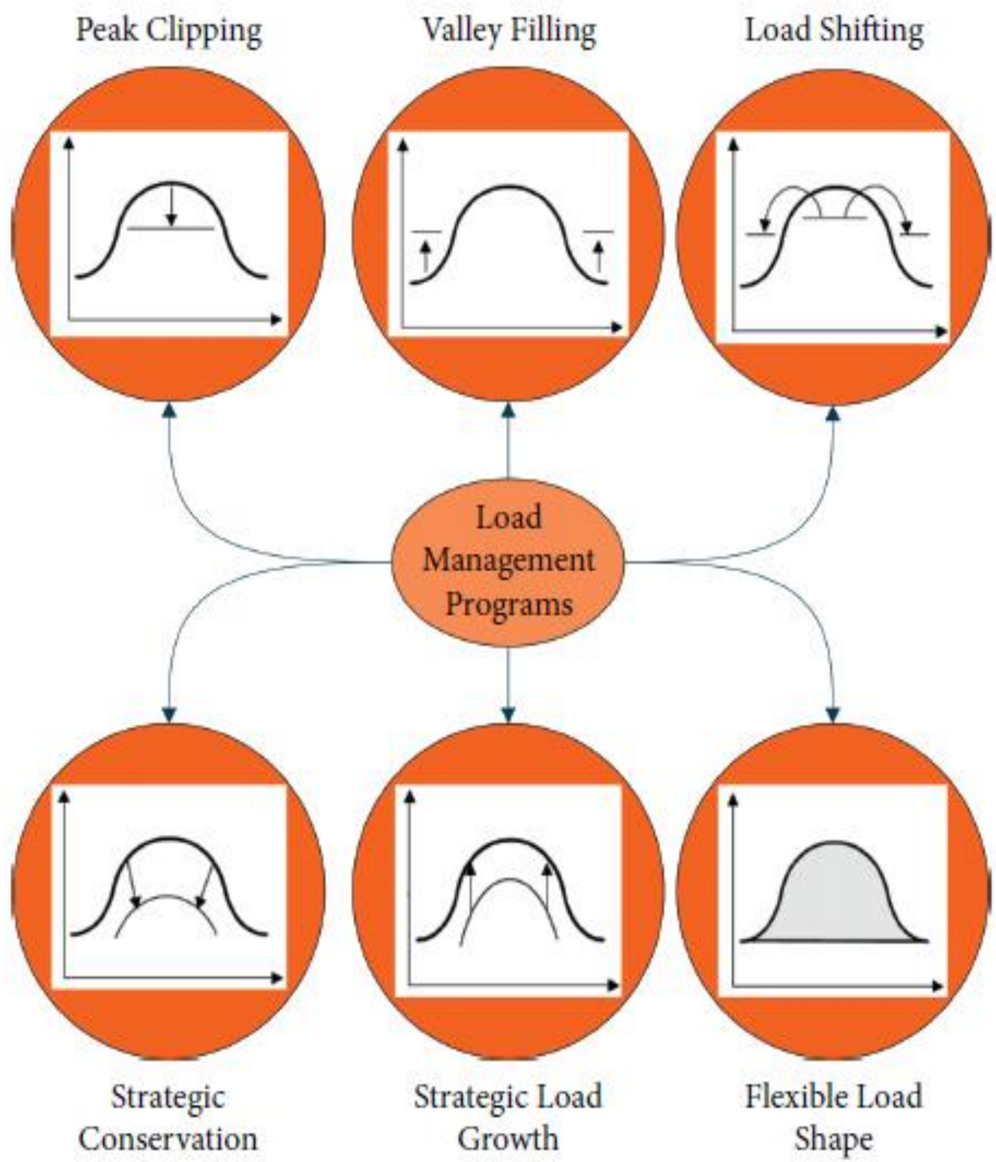
Types of DSM Methods – Load Management

Peak clipping is the process of reducing demand during peak demand periods

- It mainly focuses on the reduction of peak demand

Valley filling is the process of filling valleys (periods of low demand) to improve the system load factor

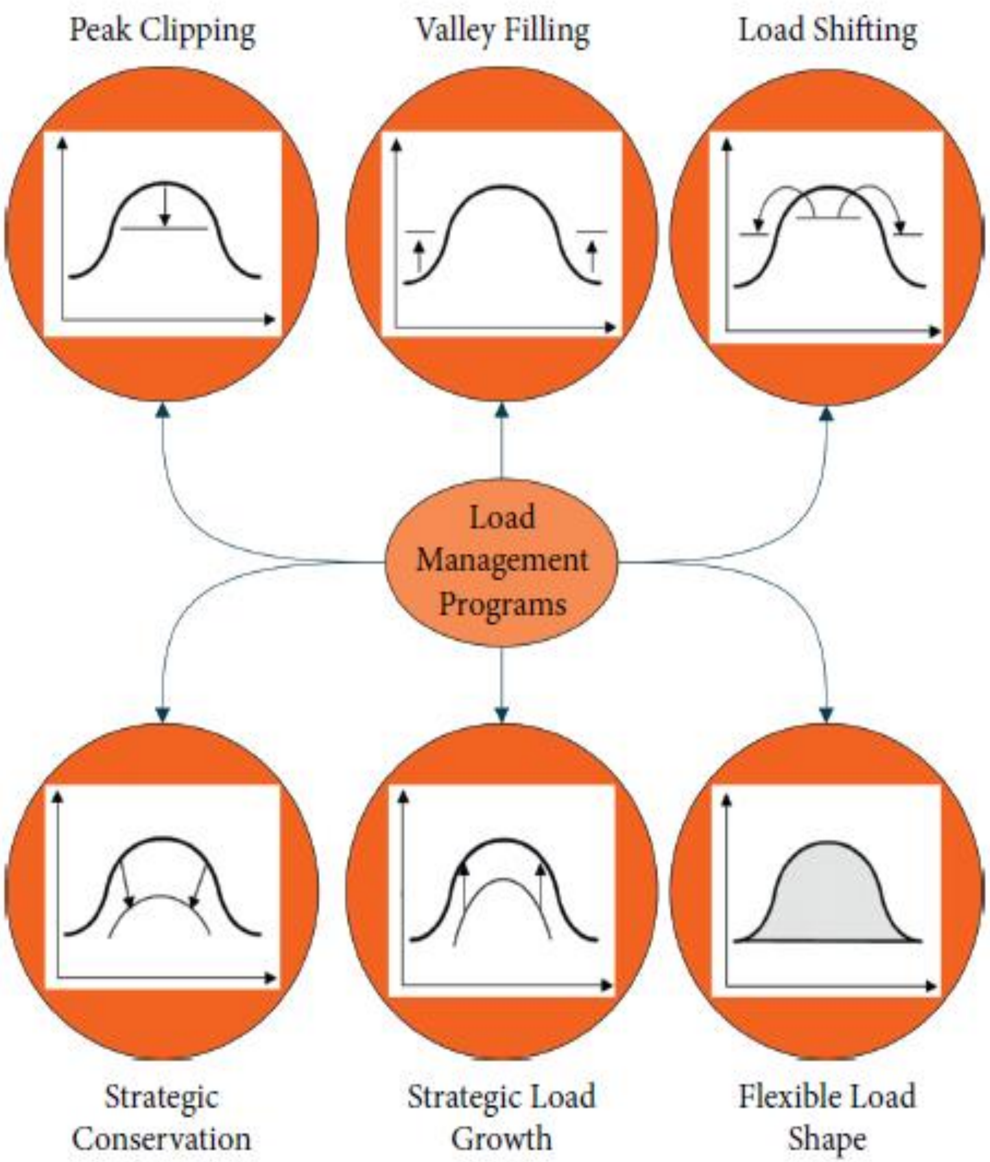
In load shifting, the loads are shifted from peak periods to off-peak periods



Types of DSM Methods – Load Management

Strategic conservation is the reduction in load caused by a decrease in overall energy consumption utilizing energy efficient appliances or measures that minimize consumers' energy needs

Strategic load growth refers to an increase in load caused by an increase in overall energy consumption, aimed at increasing electricity sales



Types of DSM Methods – Load Management

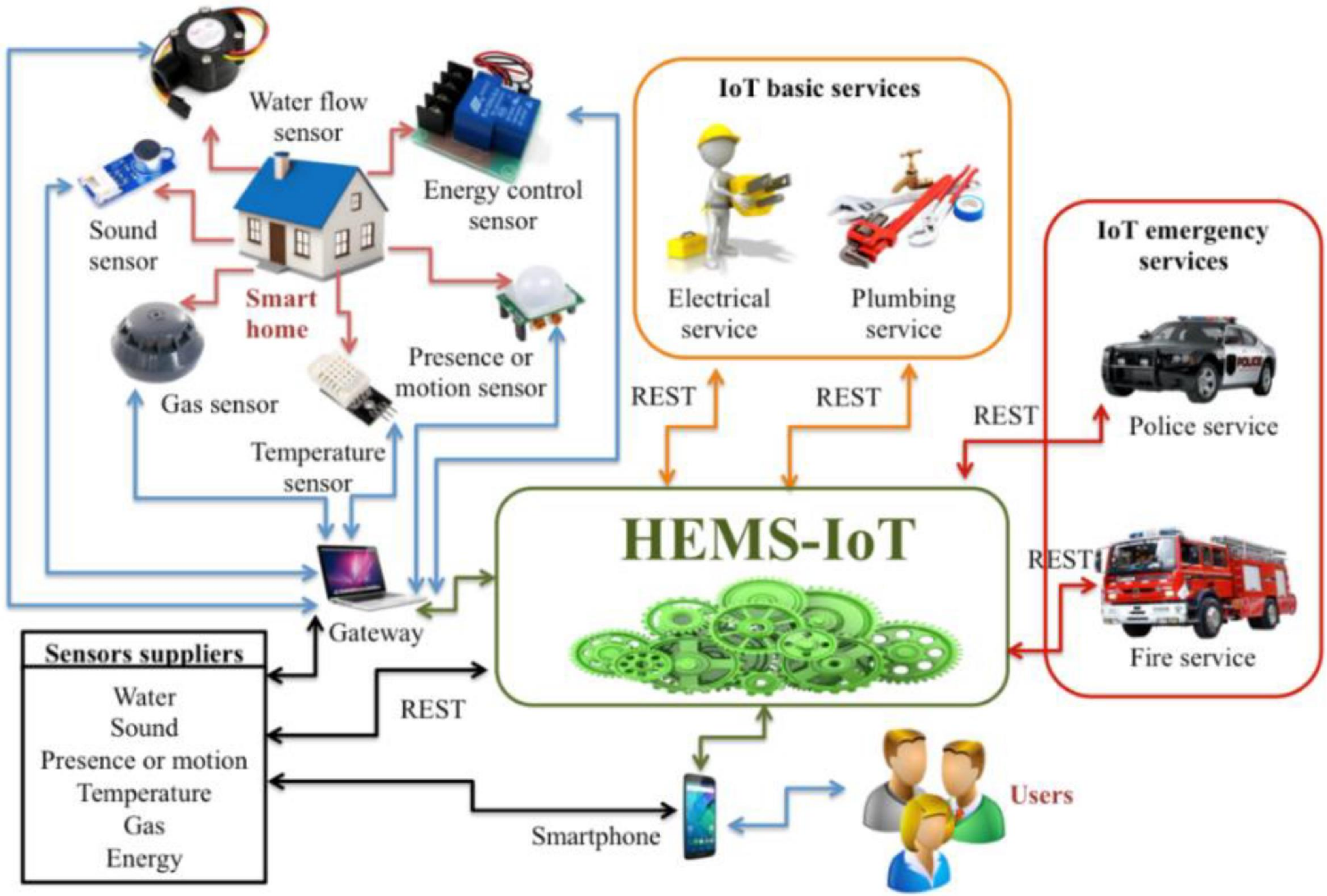
Load shifting DSM algorithms involving optimization technique, ANN, Fuzzy, and AI techniques can implemented in “home energy management system (HEMS)” to manage load demand of a smart home in real-time and day-ahead basis through coordination among home appliances during peak and non-peak hours

These techniques take into account three pricing schemes:

- time of use pricing
- critical peak pricing
- and real-time pricing

The purpose is to reduce the energy prices and peak to average ratio without destroying consumer comfort level

Types of DSM Methods – HEMS



Representational State Transfer (**REST**) – Web service

DSM in MGs with RES, DERs, ESSs

An efficient DSM method is used for smoothing variations in power using the demand response of a large no of flexible residential appliances

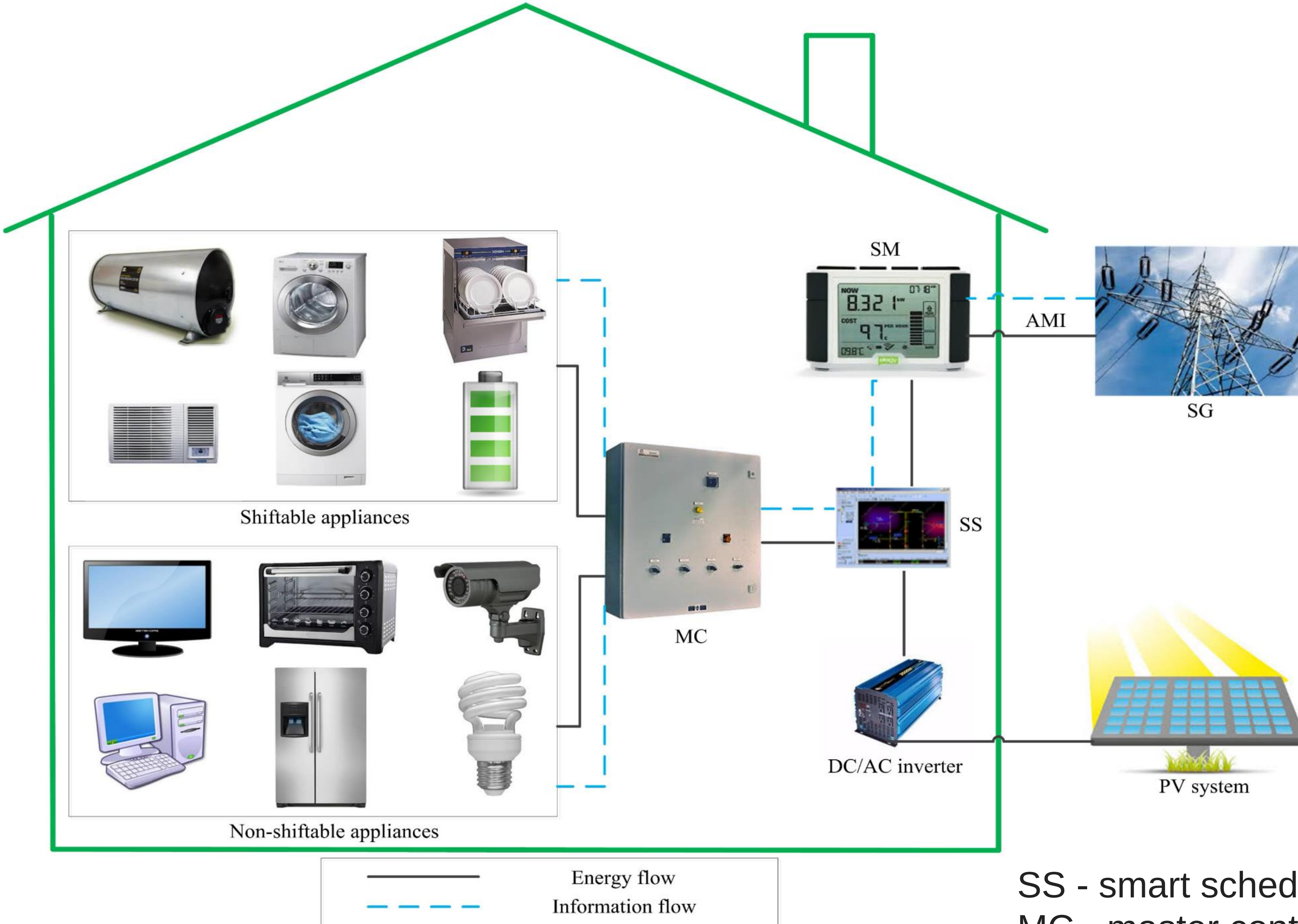
A resource scheduling algorithm is implemented as a part of home DSM for efficiently using the energy generated to reduce the cost of energy consumption of individual user

Effective DSM with roof-top PV reduce the electricity consumption cost and reliance on importing energy from the grid

The renewable generation is predicted using an effectively designed real-time prediction system

DSM for households in smart grid, provided with distributed generation and energy storage systems, through optimization and artificial intelligence (AI) to manage the battery

DSM in MGs with RES, DERs, ESSs



SS - smart scheduler
MC - master controller

DSM in MGs with RES, DERs, ESSs

The environmental and economic impacts of DER system with multiple energy sources are reduced through optimal operation scheduling of the DER system

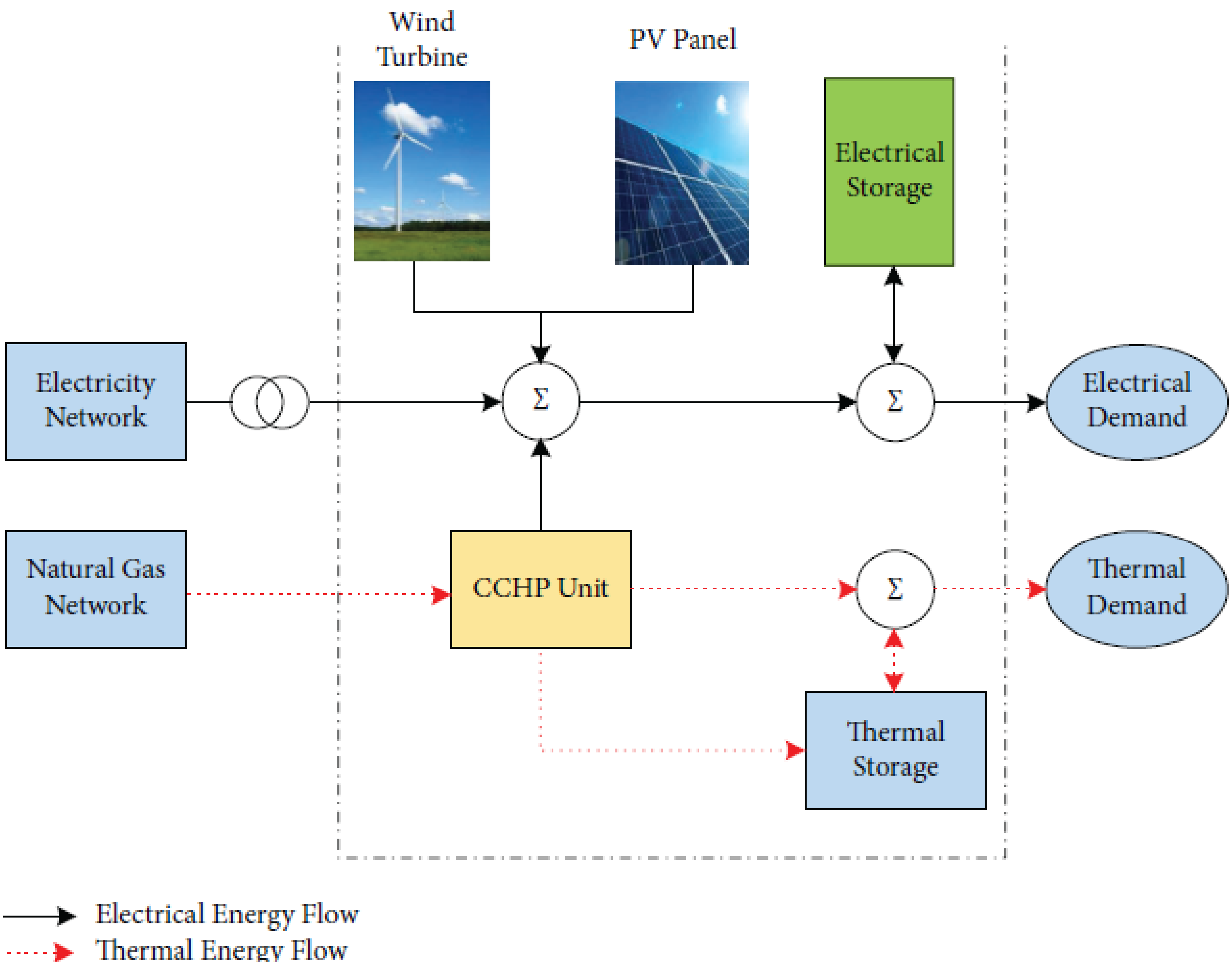
DERs has led to the creation of energy hubs

The aim of these energy hubs is the interaction among multi-energy carriers through the grid

A method for optimal scheduling of multi-energy hubs has been included as a part of community DSM for minimizing the cost of energy hubs

Moreover, using energy from clean energy resources such as solar PV and windmill in the energy hubs instead of gas-fired system over the scheduling horizon has led to the reduction in greenhouse gas (GHG) emission

DSM in MGs with RES, DERs, ESSs



DSM in MGs with RES, DERs, ESSs

Energy storage devices are also used for storing excess energy

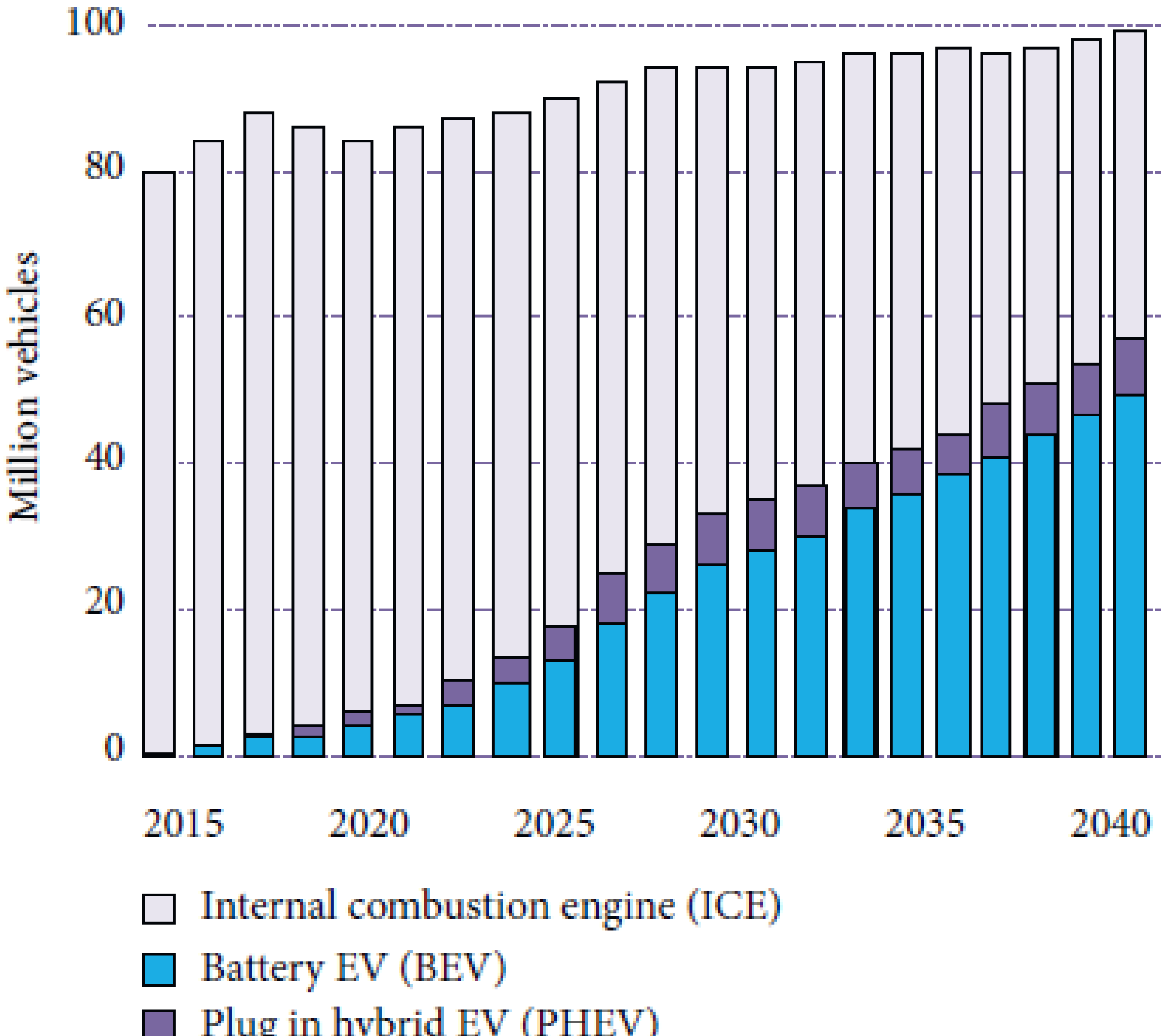
A battery scheduling algorithm is implemented as a part of home DSM to select the suitable size of battery for increasing the savings

The optimization problem needs to take into consideration:

- the costs and operational constraints of battery
- the power requirements and service duration of individual load
- minimum/average delay requirements

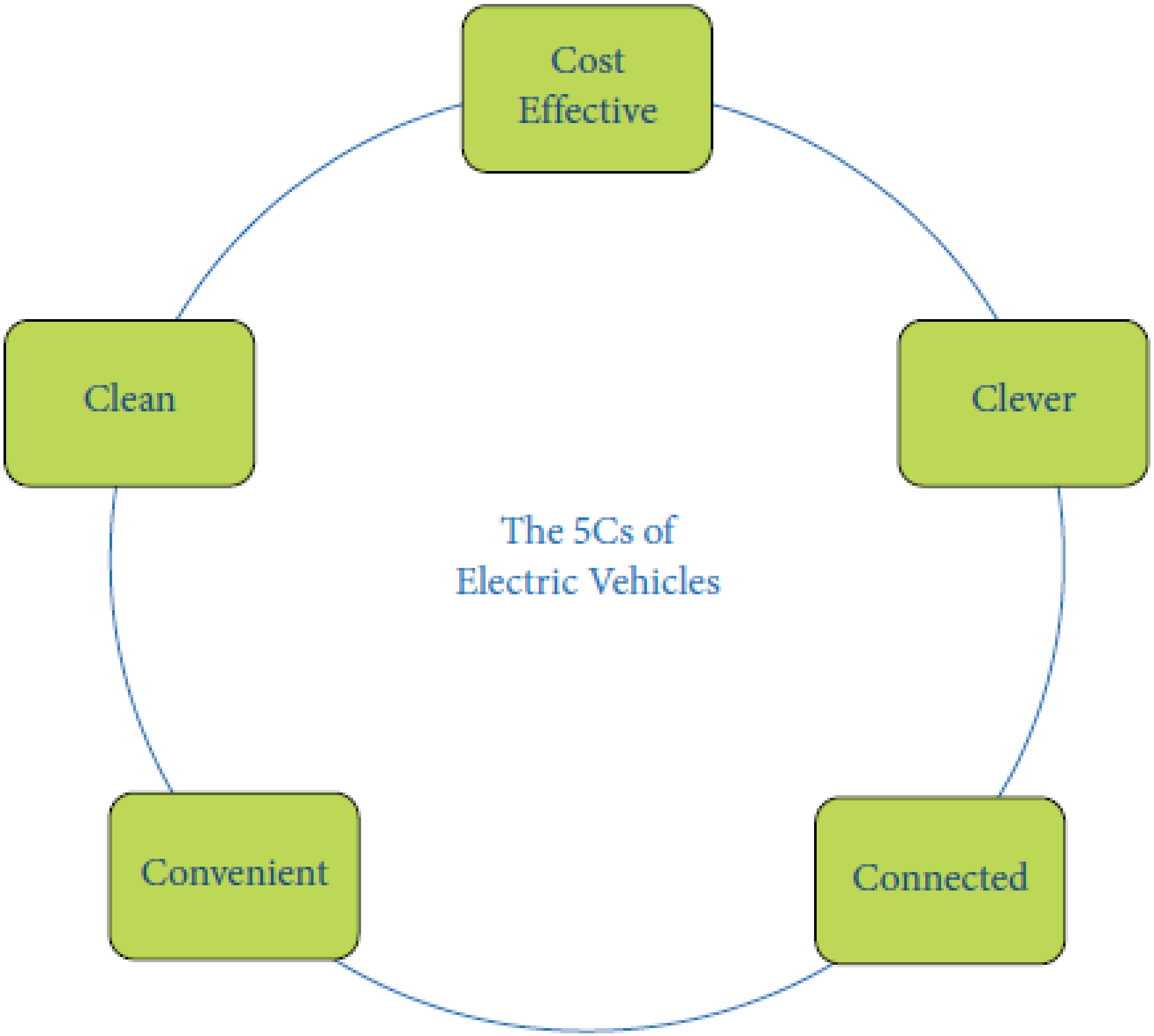
DSM in systems with EV

EVs are gaining immense popularity due to drastic environmental pollution and energy restriction conditions



DSM in systems with EV

The 5 Cs of EV



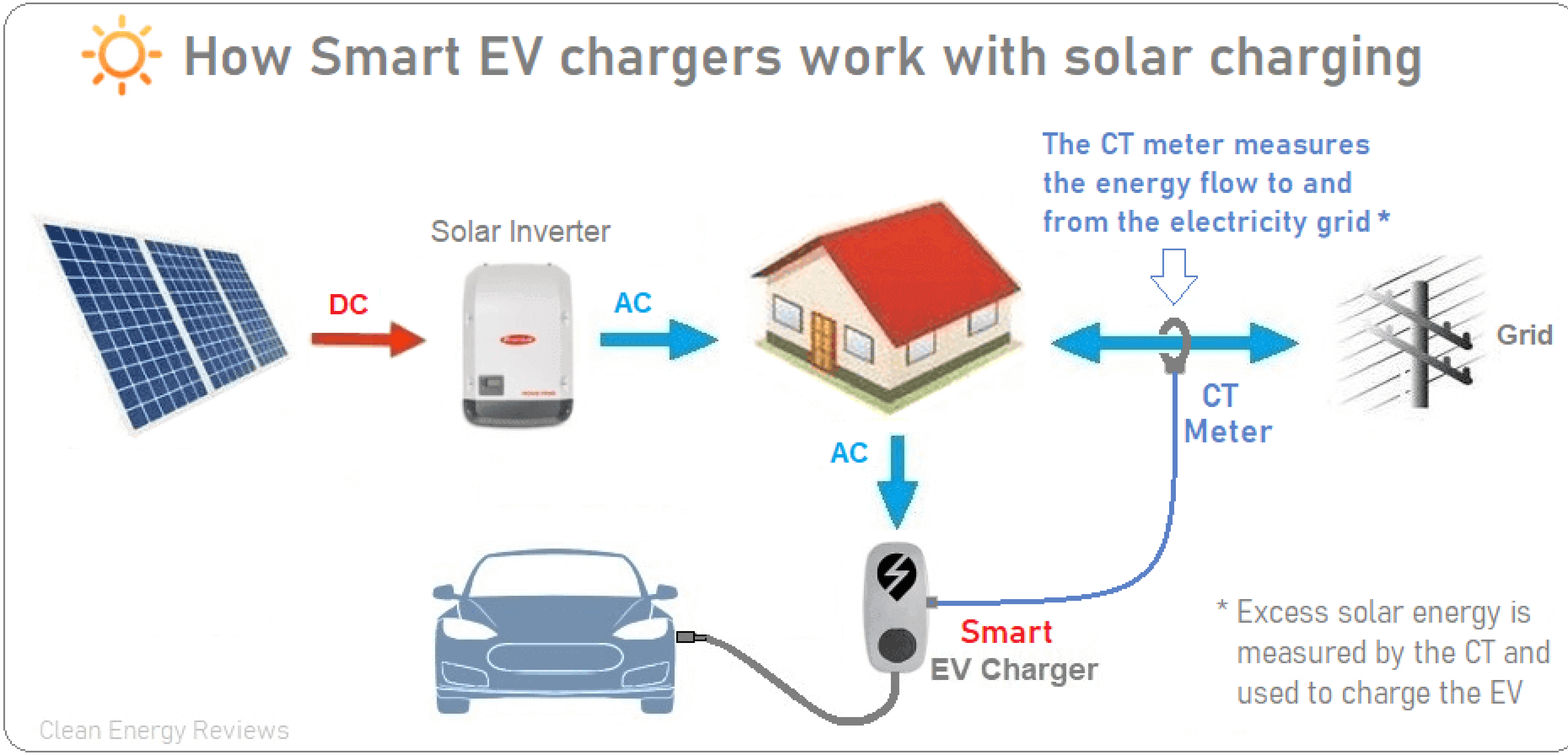
DSM in systems with EV

EV is used as a DSM tool to reduce the fluctuation in solar PV generation

Three parameters control the behavior of EV acting as load or source

- These three parameters are PV output, State of charge (SOC), and system voltage
- To overcome the variable and intermittent nature of solar PV, EVs can be used as source for peak shaving and as load for valley filling
- Conditions of low and high voltages can be mitigated, and high energy generation is utilized by incorporating EV as a DSM tool

DSM in systems with EV



DSM in systems with EV

One more objective of an effective DSM with EV is to take into account the charging and discharging constraints of charging stations

An optimization technique is used to recognize the orderly charging and discharging pattern of EVs

An intelligent charging strategy using machine learning (ML) can be used for making real-time charging decisions for EVs depending on conditions like environment, pricing, driving, and demand times

DSM in systems with EV

Integrating the EVs in grid results in voltage fluctuations and an increase in cost of deployment of charging setup to meet the peak demand for charging

DSM schemes can be employed for reduction in cost and peak demand for charging

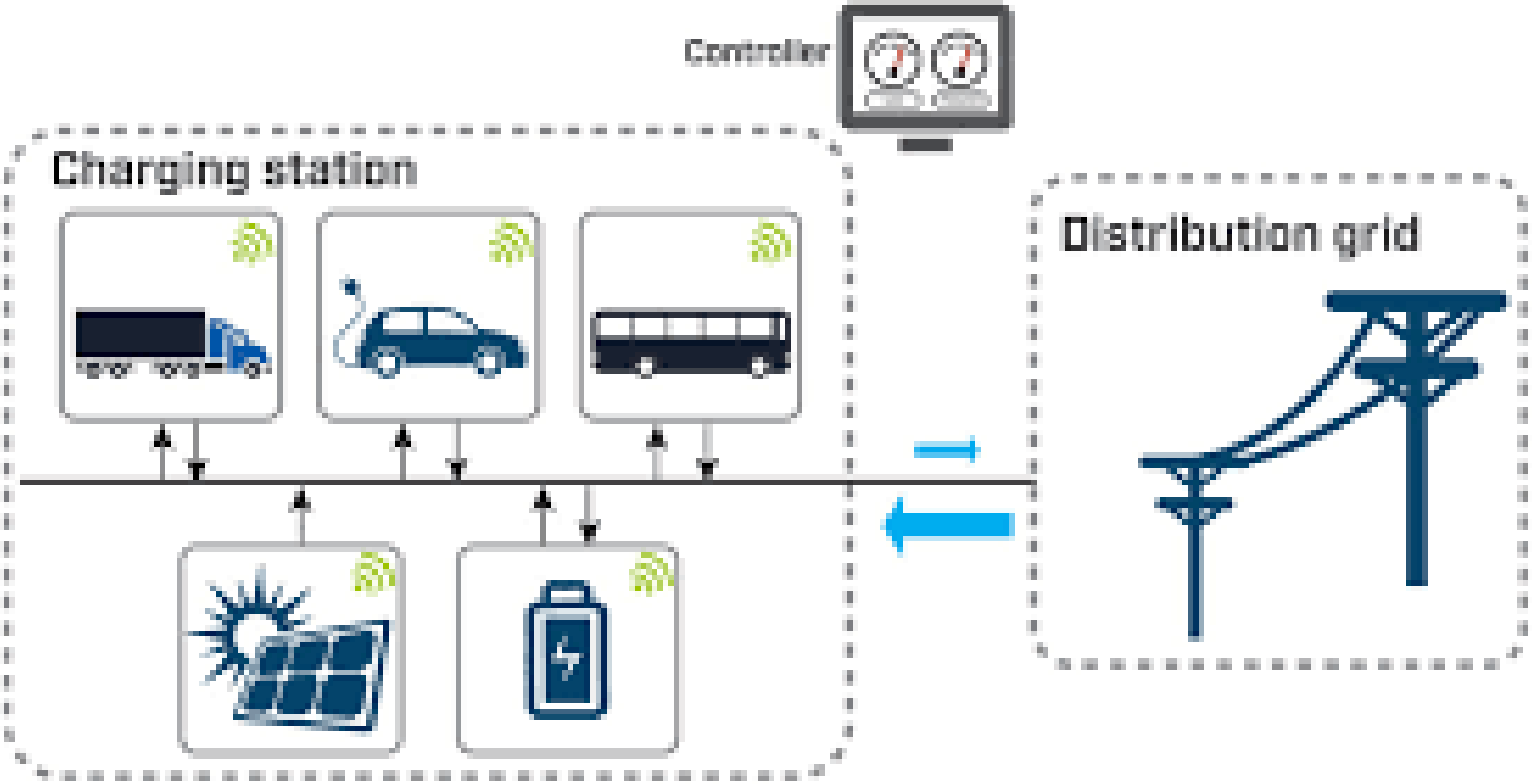
However, maximizing the charging capacity while minimizing the cost is a perplexing task leading to tripartite game among EV battery service provider, EV owners, and government

Solutions can be optimization between

- plug-in charging
- battery-swapping mode
- on-the-go charging models

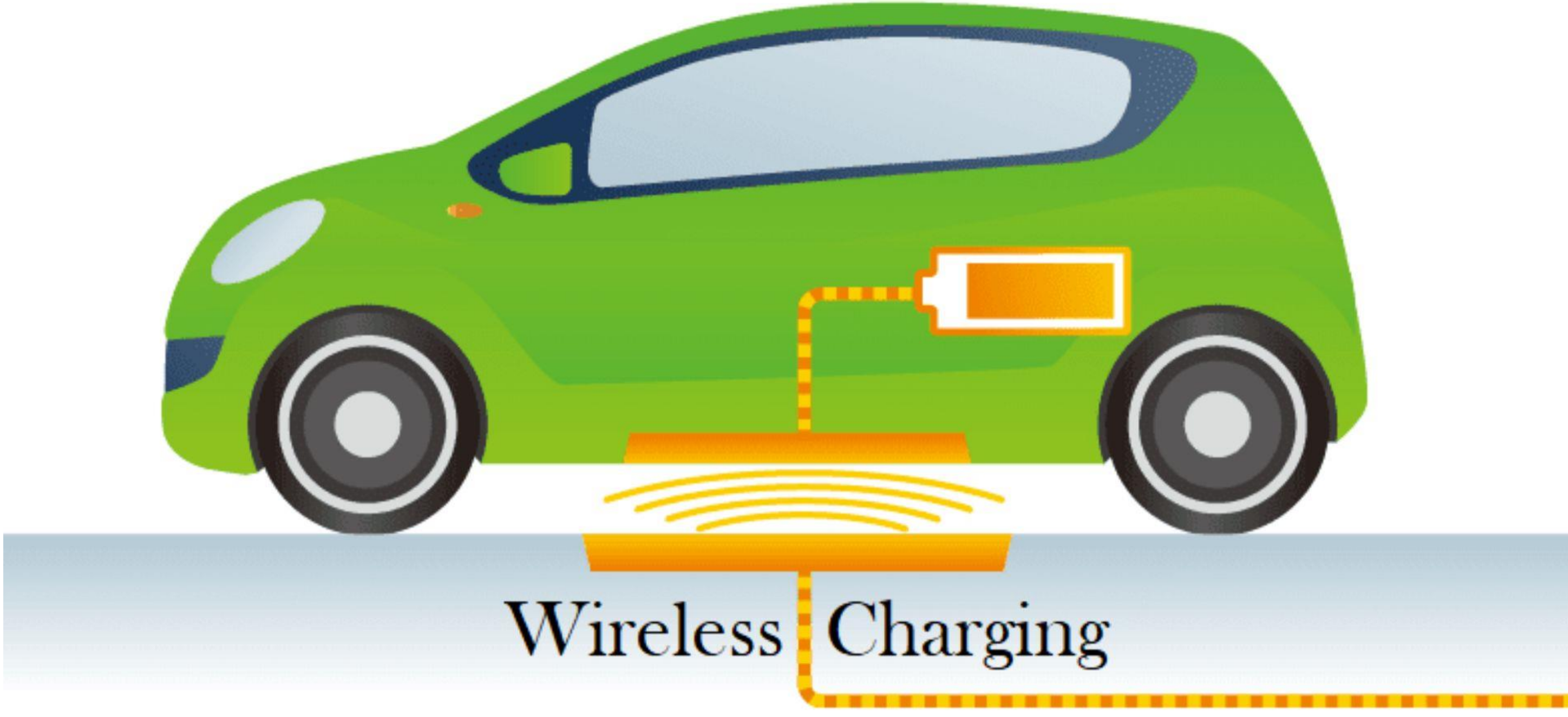
DSM in systems with EV

DSM in systems with EV



DSM in systems with EV

DSM in systems with EV



DSM in systems with EV

DSM in systems with EV

Due to frequent charging of EVs in residential areas, the distribution system has to face new load requirements

A separate DSM strategy is to be employed to overcome the stress on distribution network presented by EVs

DSM is intended to satisfy the PV owners' charging rquirements with the constraints of reducing the overall load on the transformer and thermal stresses on the conductor

The most frequently used constraints for DSMs with EVs are:

- State of charge (SOC) of EV
- Charging and discharging constraints of PEVs
- Power system constraints
- Power battery constraints

Demand Response Management (DRM)

Demand Response Management (DRM)

DR in smart grid can be defined as the rescheduling of the users' energy usage patterns in response to the variance of the power utility's incentive or electricity price, which is designed to reduce the demand at peak time periods or during system contingencies

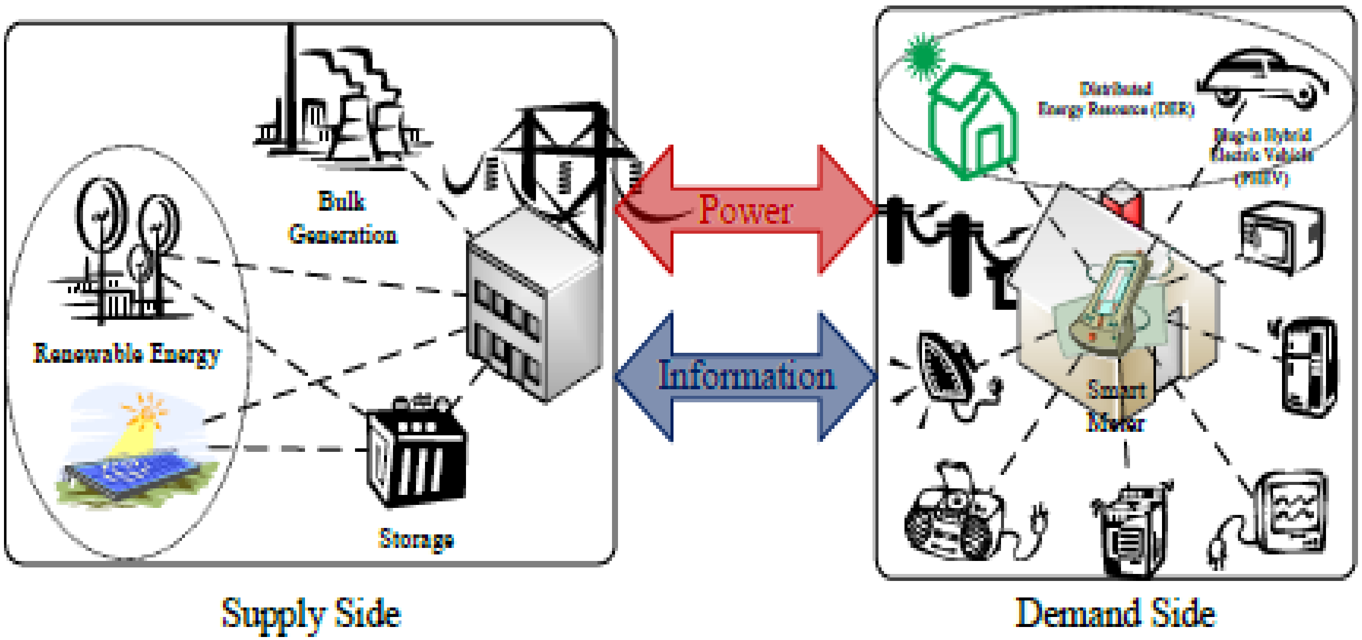
By having smart meters installed at users' premises and two-way communications enabled between the power utility and users, demand response becomes an essential characteristic of the smart grid (including the microgrid), with the ability to shape the users' electricity loads in an automated and convenient fashion

The demand response capability of the smart grid, in essence, enables the supply and demand sides to interact with each other by exchanging the price and demand information, in order to make wise decisions

When users are provided with sufficient incentives, they are willing to change their energy usage patterns to tradeoff between comfort and electricity bills

Features of DR

The introduction of smart metering and availability of bi-directional communications are two main technical drivers for incorporating demand response into smart grids.

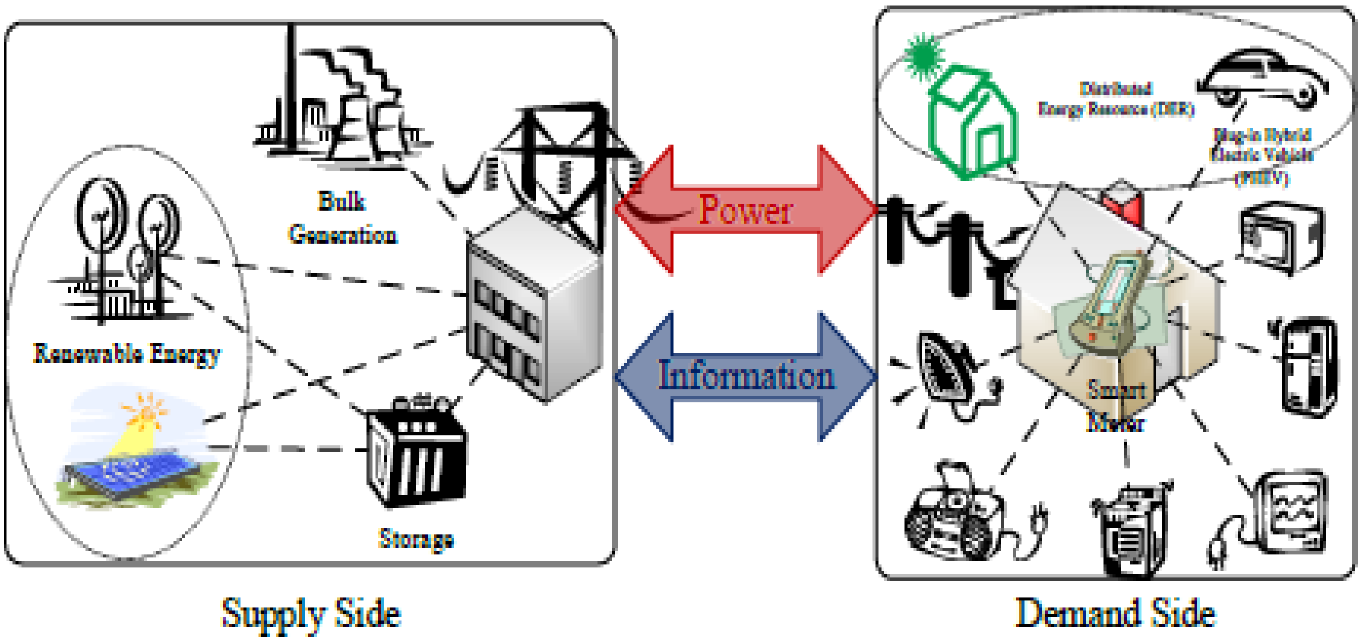


Features of DR

The mechanism of demand response involves the interaction between the supply and demand sides by two-way flows of power and information

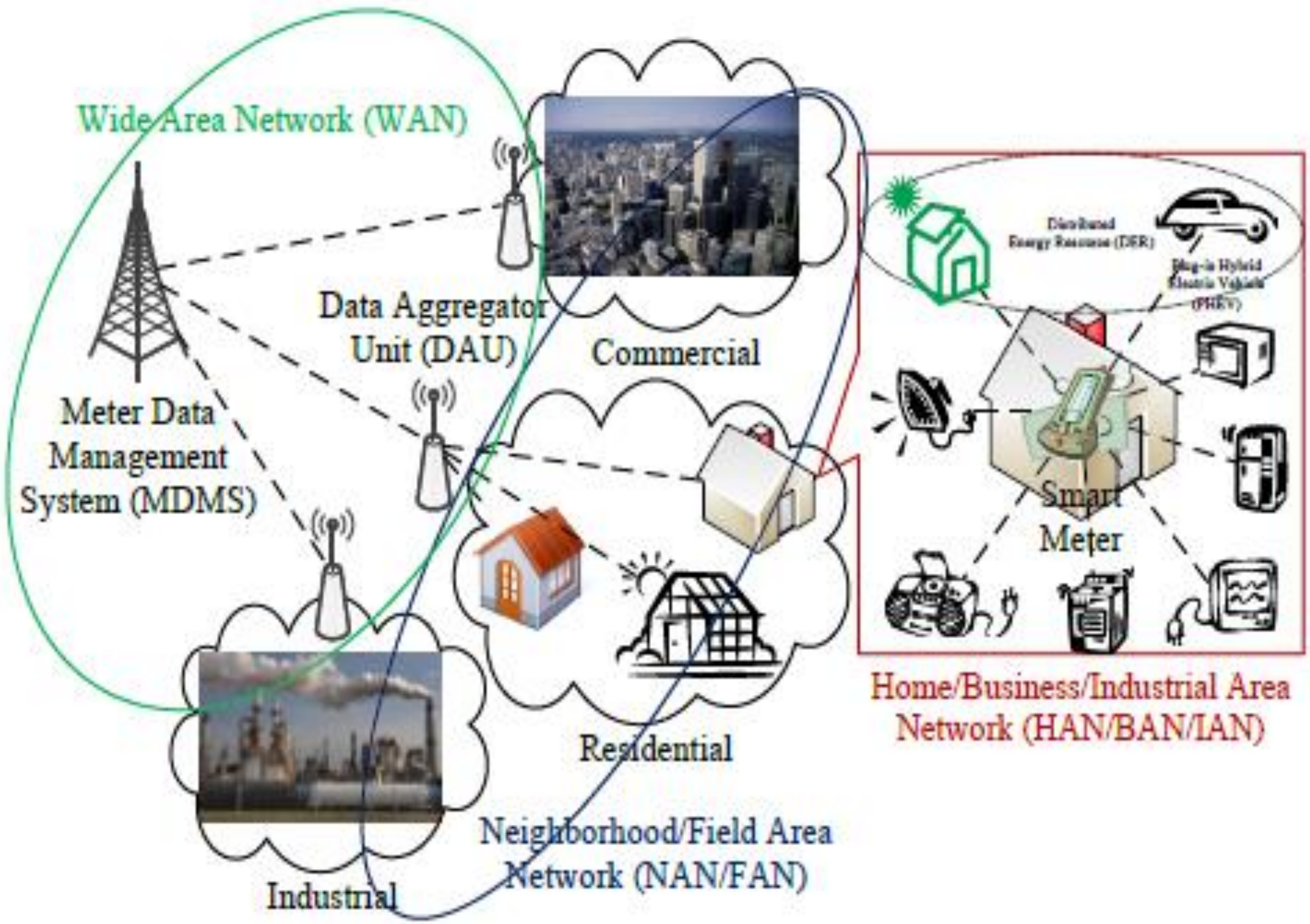
Two operational modes, grid-connected and islanded, enable the microgrid being a "prosumer" (producer and consumer) in the smart grid

Up to now, a variety of smart grid pilots involving demand response research projects and industrial cases are developed or under development all over the world, including U.S., Canada, China, Germany, Japan, Australia, etc.



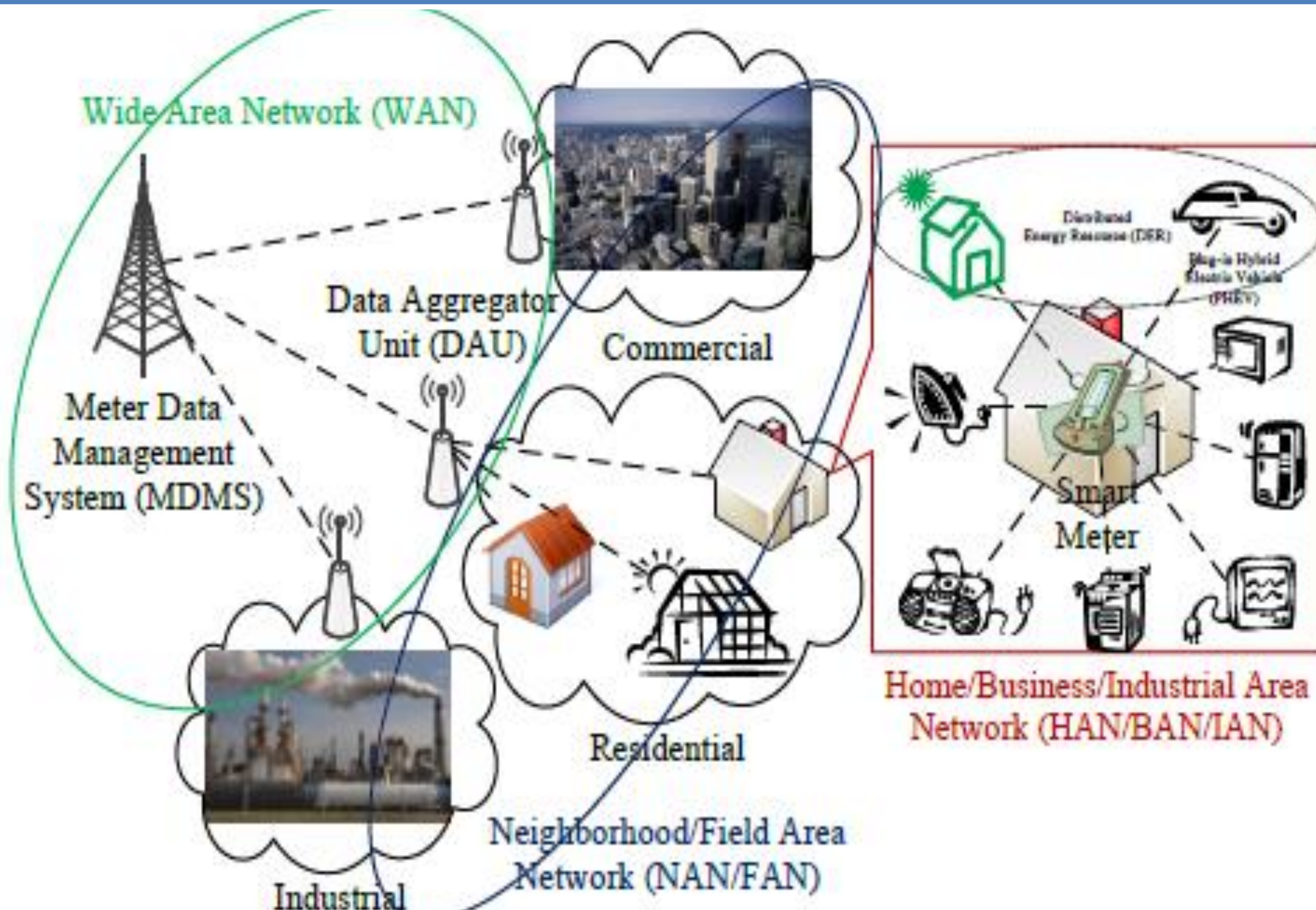
Communication Standards for DR

Three types of communication networks different in size and location coexist in the smart grid, with a variety of communication standards and technologies



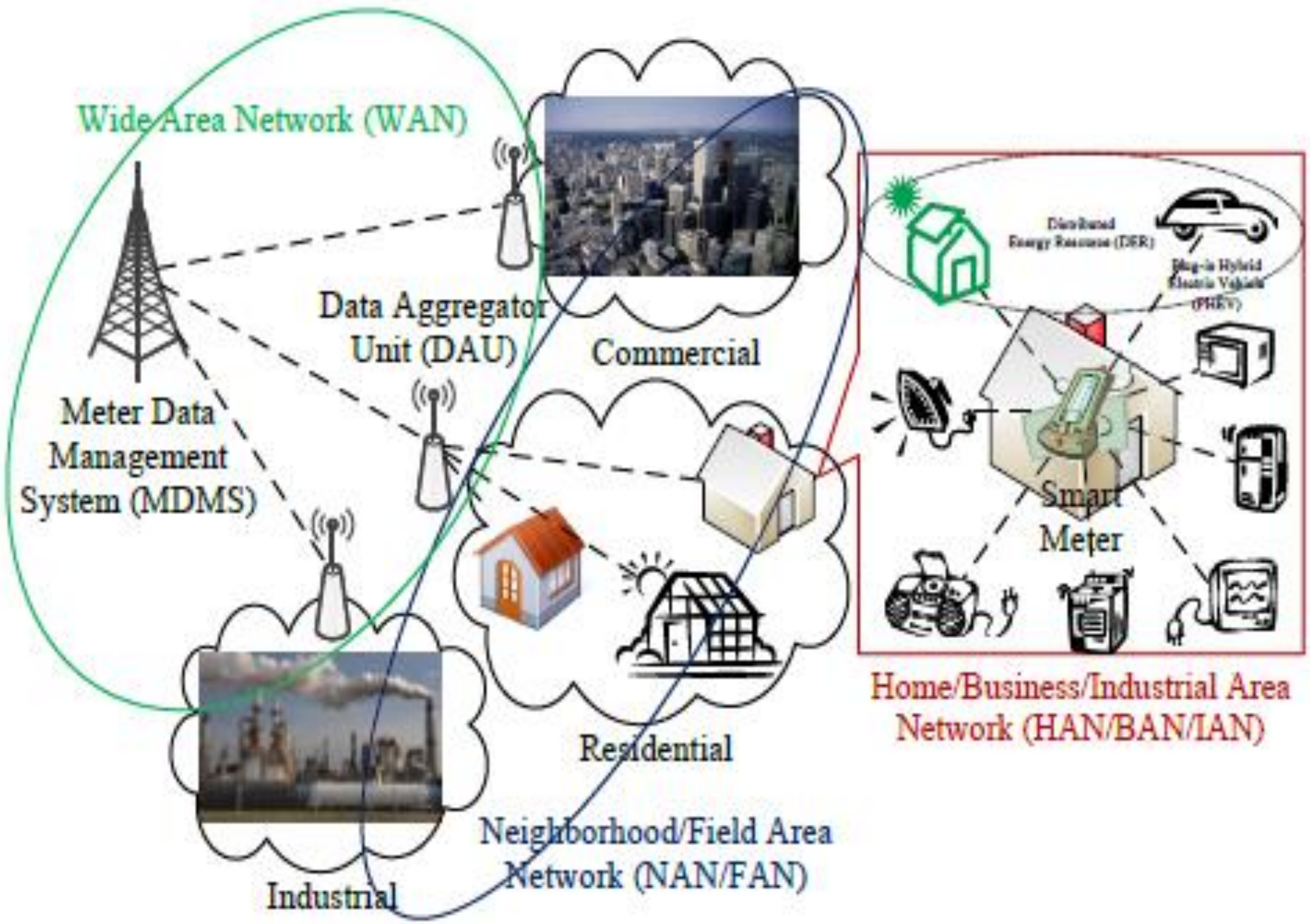
Communication Standards for DR

Home/business/industrial area networks (HAN/BAN/IAN) are deployed within residential units, commercial buildings, and industrial plants for connecting multiple electrical appliances to smart meter through IEEE 802.15.4 (ZigBee), IEEE 802.11 (WiFi), or power line carrier communication(PLCC)



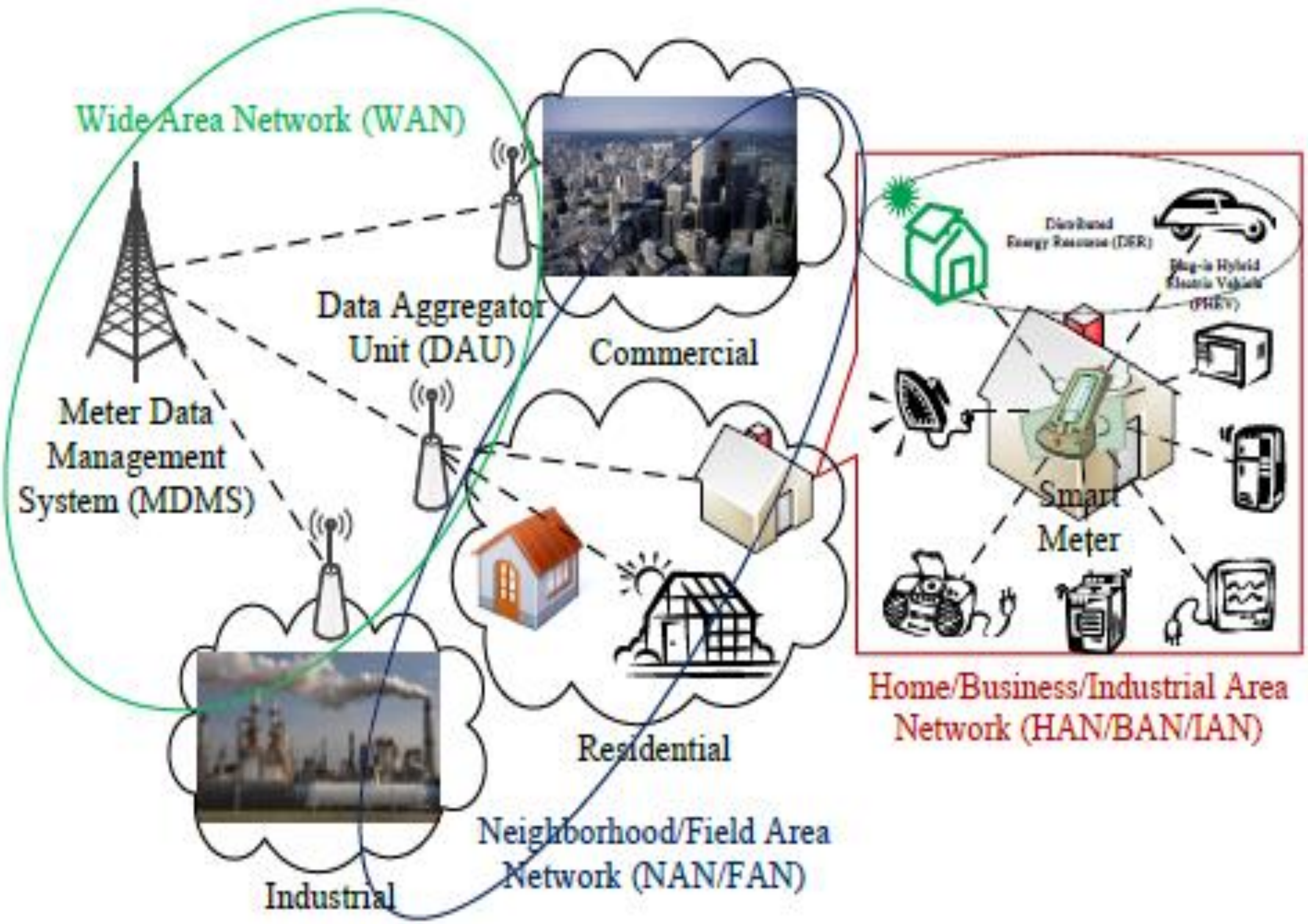
Communication Standards for DR

Neighborhood/field area networks (NAN/FAN) support communications among distribution substations and field electrical devices for power distribution system and microgrid operation



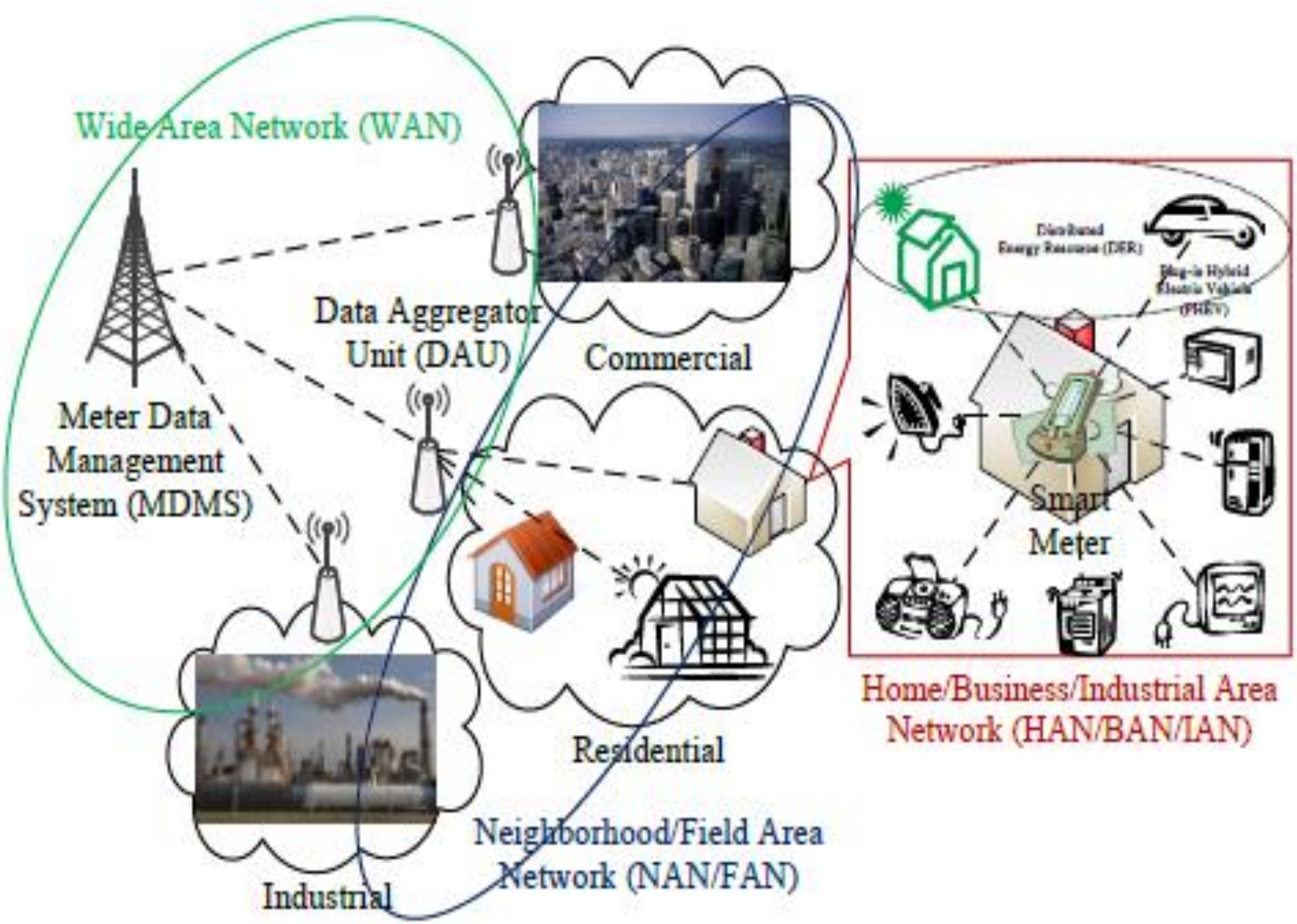
Communication Standards for DR

NAN/FAN connect multiple smart meters to data aggregate unit (DAU) through IEEE 802.11 (WiFi), IEEE 802.16m (WiMax), or cellular networks (e.g., GPRS, 3G, and LTE)



Communication Standards for DR

Wide area networks (WAN) facilitate communications among bulk generation, power transmission system, and meter data management system (MDMS) through fiber-optic communication, microwave transmission, or cellular networks



DR Programs

Demand response programs can be considered as the means or tariffs that the power utility takes to incentivize users to reschedule their energy usage patterns

In other words, the programs are able to shape the users' electricity load profiles in order to improve the reliability and efficiency of the grid

Demand response programs are mainly divided into the following two branches

- Incentive-based Program
- Price-based Program

Incentive-based DR Program

Incentive-based program pays participating users for demand reduction, triggered by peak load or system contingencies

This program provides these users with load modification incentives, which is in addition to or separate from electricity prices

Several main programs are:

- Direct load control (DLC)
- Interruptible/curtailable load
- Demand bidding & buyback
- Emergency demand reduction

Incentive-based DR Program

Direct load control (DLC)

- The power utility has remote access to/control of (shut down or cycle) certain electrical appliances/energy loads (e.g., air conditioner, water heater) of users whenever needed, on condition that the participating users are provided with incentive payments
- The key idea is to reduce the load at peak hours
- DLC has been offered to residential and small commercial users for decades

Interruptible/curtailable load

- If users agree to cut down some portion of their interruptible / curtailable loads when the grid reliability is jeopardized, they will receive a certain incentive discount on electricity bills in return

Incentive-based DR Program

Demand bidding & buyback

- In the case of peak demand or system contingencies, users can benefit from cost saving if they are willing to curtail some electricity usage at a specific bid price
- This program is mainly offered to larger users (one megawatt or more); for small users, they need third parties or agents to unite and represent them to bid.

Emergency demand reduction

- Users are provided incentive payments in reply to their load reductions (on very short notice) during emergency reliability accidents when the grid is out of reserve
- Under this program, larger users can provide auxiliary services to the power utility by reducing their demand, behaving as virtual spinning reserves

Price-based DR Program

An alternative to the legacy flat electricity prices is smart pricing

Price-based program provides users with different electricity prices at different times

Based on such information, users will naturally use less electricity when electricity prices are high, and thus reduce the demand at peak hours

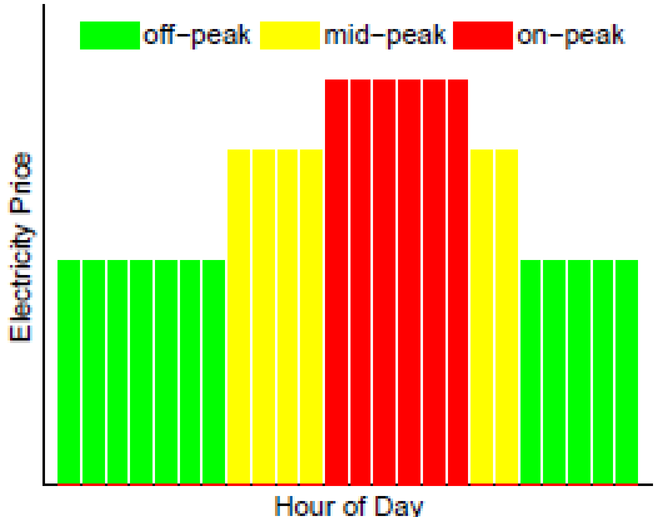
Various time-based pricing tariffs are:

- Time-of-use (ToU) pricing
- Critical peak pricing (CPP)
- Real-time pricing (RTP)
- Inclining block rate (IBR)

Price-based DR Program

Time-of-use (ToU) pricing

- When users consume energy at different time intervals of a day, or different seasons of a year, they are charged at different electricity prices
- Typically, each time period is longer than one hour
- For example, the three-level (on-peak, mid-peak, off-peak) time blocks based ToU pricing is employed some places (different in summer and winter)
- The electricity price at the on-peak time block is much higher than that at the mid-peak and off-peak time blocks, in order to induce users to shift their loads over the time horizon
- ToU pricing is usually released far in advance, and keeps unchanged for a long time period



Price-based DR Program

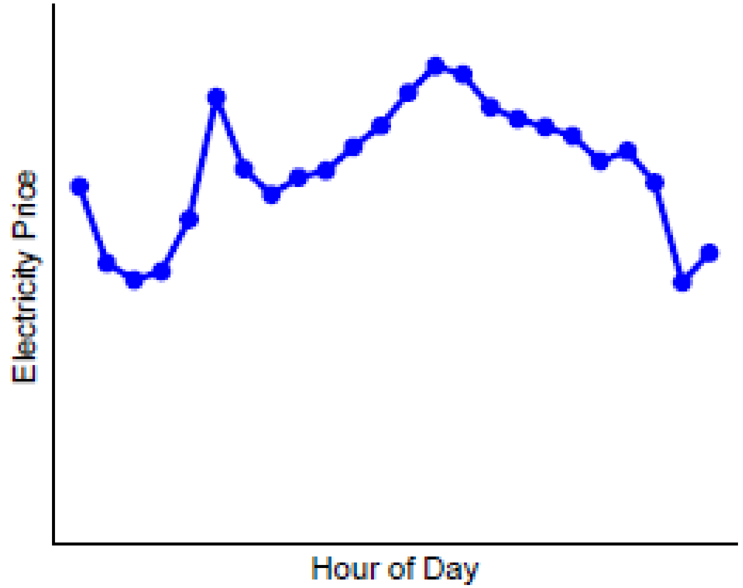
Critical peak pricing (CPP)

- The basic rate structure of this tariff is ToU pricing except for certain days, when the grid reliability is jeopardized, and then the normal peak price is replaced by a pre-specified higher rate to reduce the users' energy demand
- CPP is employed only for a limited number of hours or days per year, in order to guarantee reliability for system or balance demand with supply

Price-based DR Program

Real-time pricing (RTP)

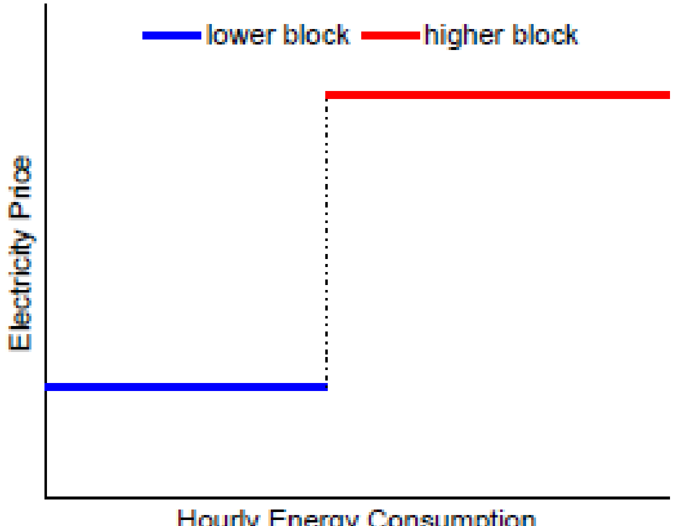
- This tariff is also referred to as dynamic pricing, where the electricity price usually varies at different time intervals of a day (in each 15 minutes or each hours)
- RTP is usually released on an hour-ahead or day-ahead (day-ahead pricing, DAP) basis
- RTP has been widely considered to be one of the most efficient and economic price-based programs



Price-based DR Program

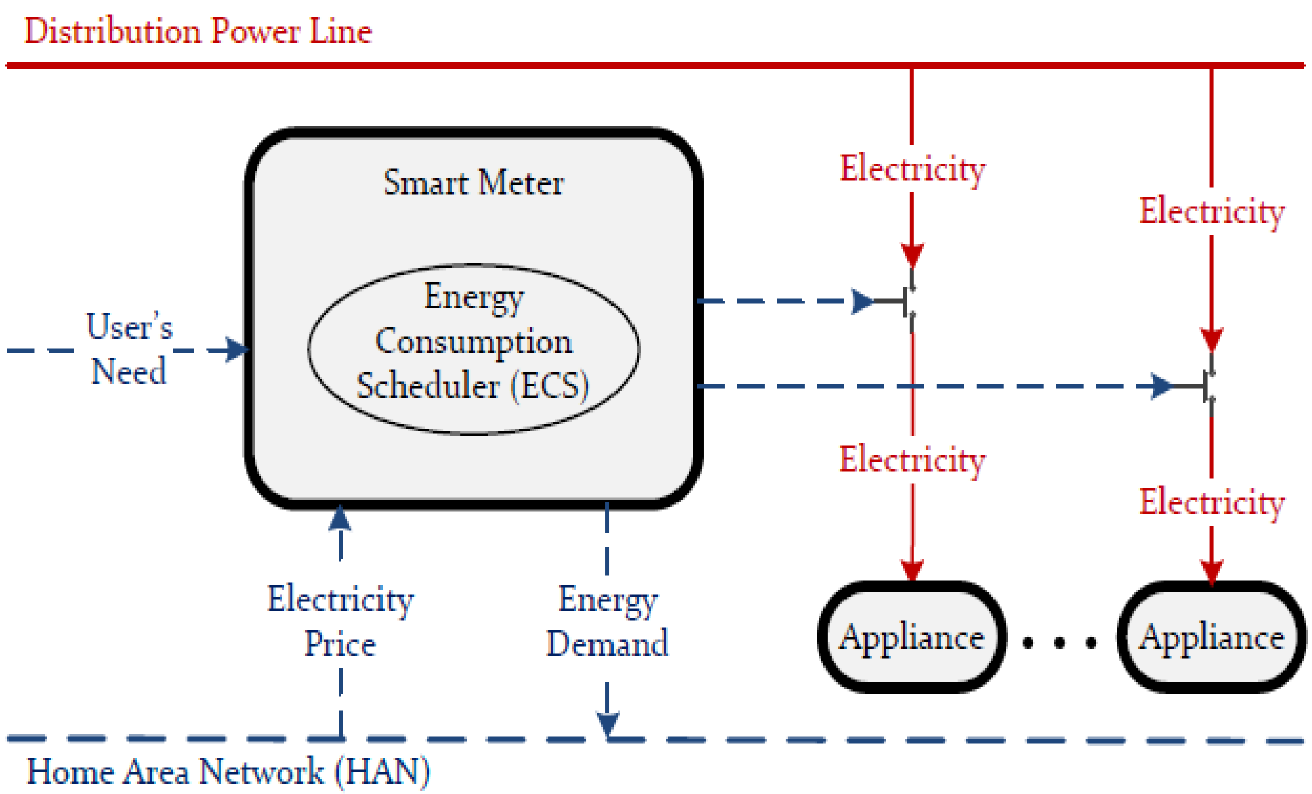
Inclining block rate (IBR)

- This tariff is designed with two-level rate structures (lower and higher blocks), such that the more electricity a user consumes, the more he pays per kWh
- In other words, the electricity price per energy consumption will climb up to a larger value if the user's hourly/daily/monthly energy consumption exceeds a certain threshold
- IBR incentivizes users to distribute their loads among different times of a day to avoid higher rates, helping reduce the grid's peak-to-average ratio (PAR)



DR Implementation in HEMS

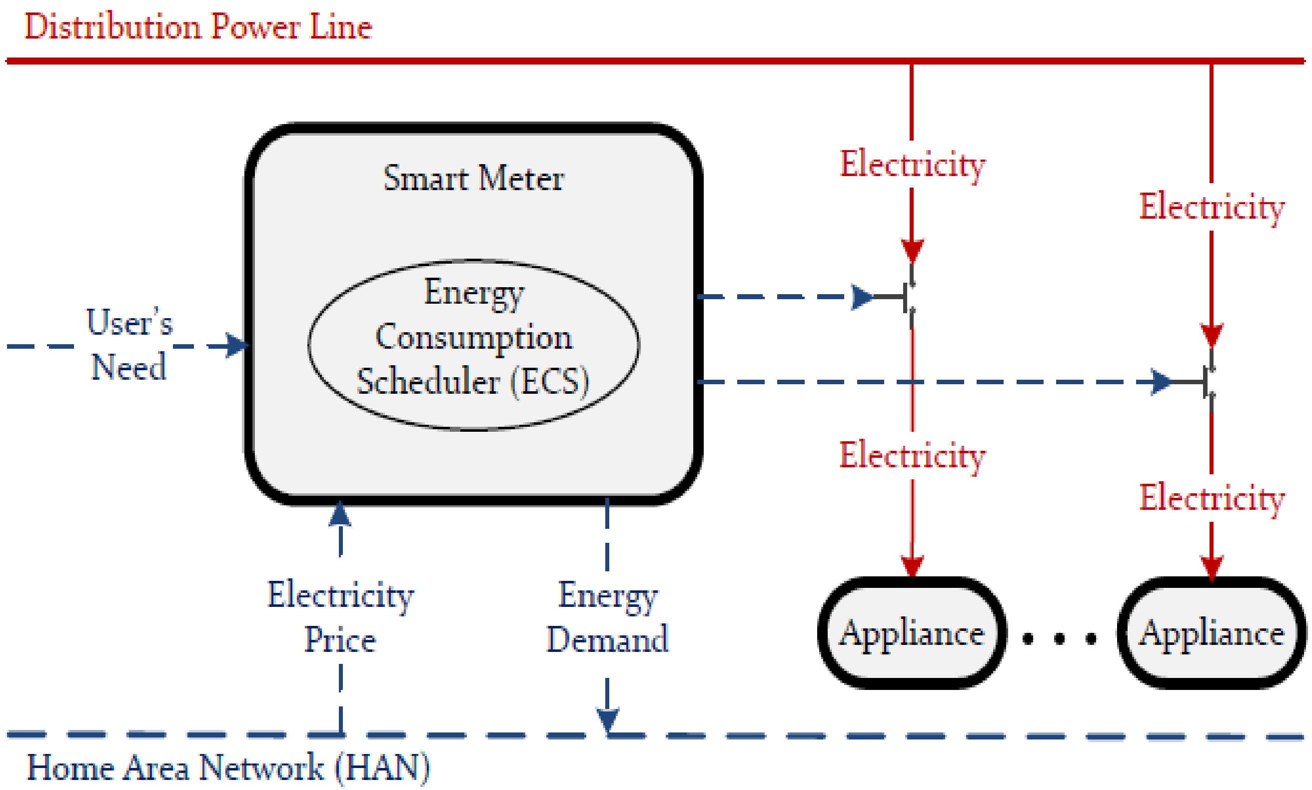
Demand response is generally performed in the residential district instead of commercial and industrial sectors, since residential users are more sensitive to the electricity price, due to more shiftable / controllable / interruptible / deferrable / flexible / elastic appliances, e.g., PHEV, washer, and dryer



DR Implementation in HEMS

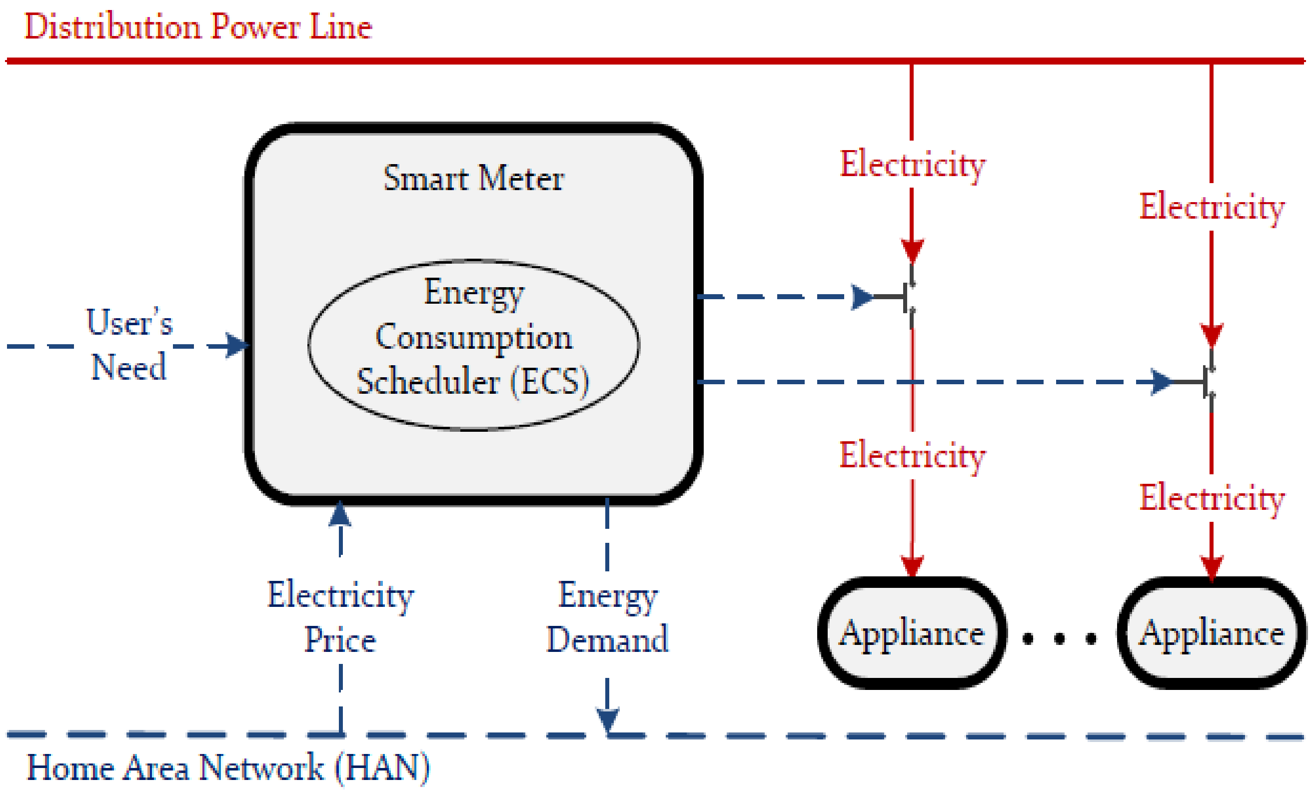
The electricity price and energy demand are exchanged via the home area network

The smart meter (with an energy consumption scheduler embedded) automatically coordinates all appliances to satisfy the user's need by demand response via on/off control commands with specified operating modes



DR Implementation in HEMS

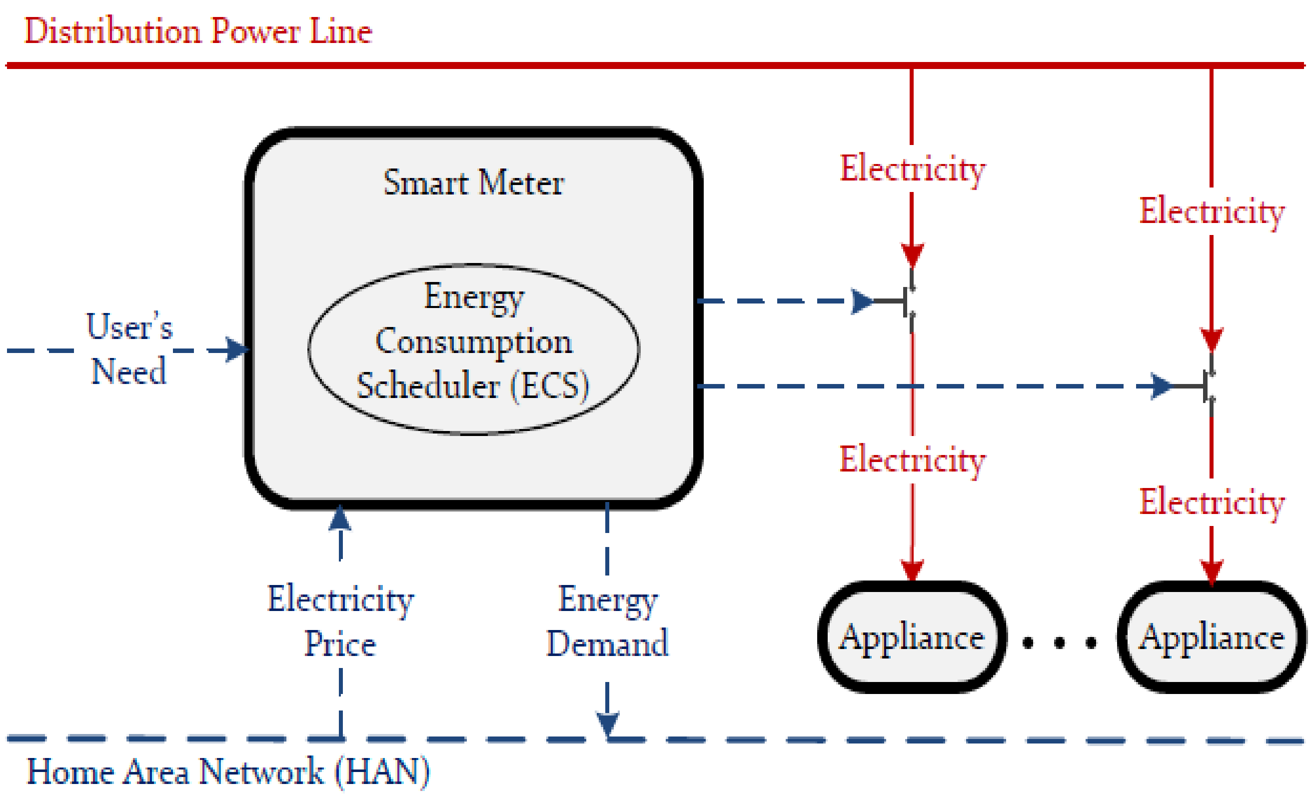
Based on two-way communications, smart metering could gather detail information of users’ electricity usage patterns and provide automatic control to household appliances, which forms the home energy management system (HEMS)



DR Implementation in HEMS

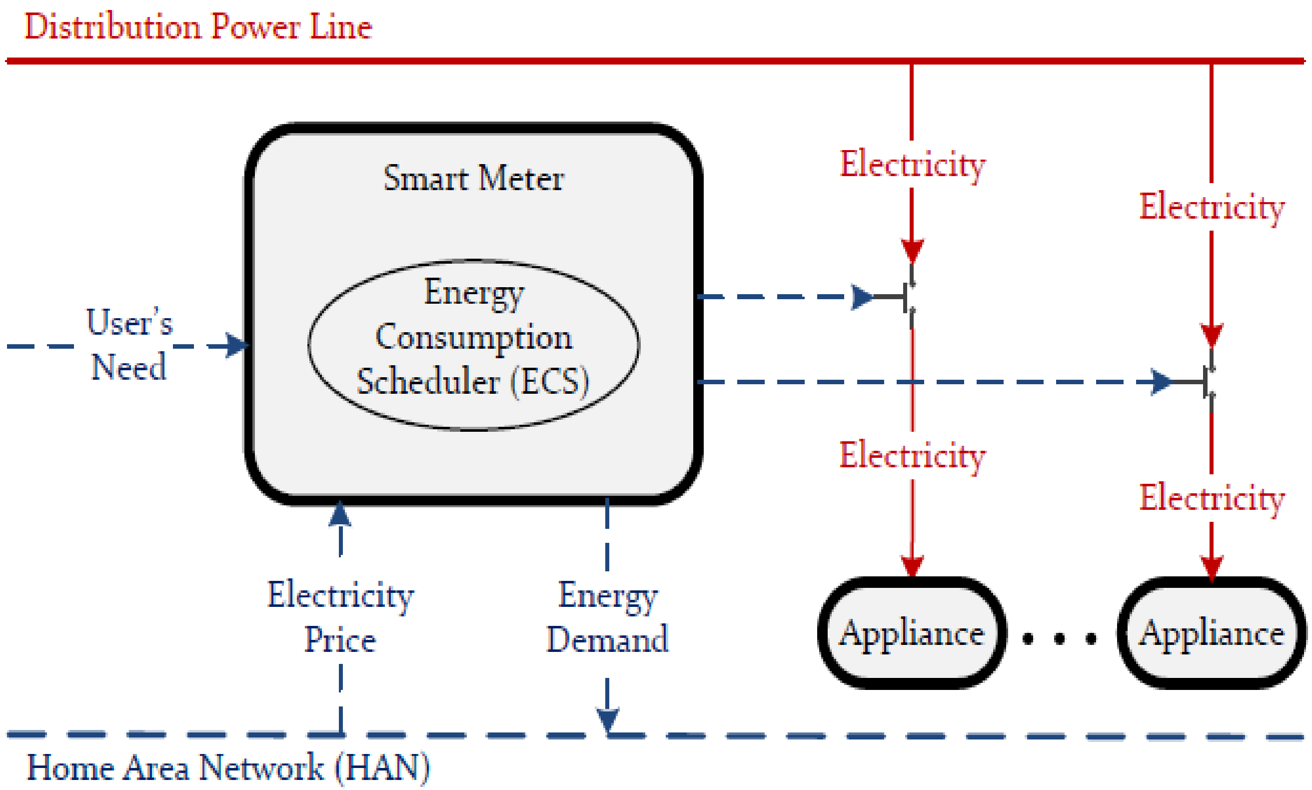
There is an energy consumption scheduler (ECS) embedded in the smart meter at each household, whose role is to control the on-off switch and operating mode of each appliance

The smart meter acts as a controller that coordinates all appliances to satisfy the user's need



DR Implementation in HEMS

After demand response, the smart meter will send on/off control commands with specified operating modes to all appliances, according to the resulting energy consumption schedule



Algorithms for DR Implementation

Demand response is usually formulated as the following mathematical problems

- Utility maximization
- Cost minimization
- Price prediction
- Renewable energy scheduling
- Energy storage scheduling

Demand response is usually formulated as optimization problems, which are solve by various approaches

- Convex Optimization
- Game Theory
- Dynamic Programming
- Markov Decision Process
- Stochastic Programming
- Particle Swarm Optimization