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SMART DISTRIBUTION

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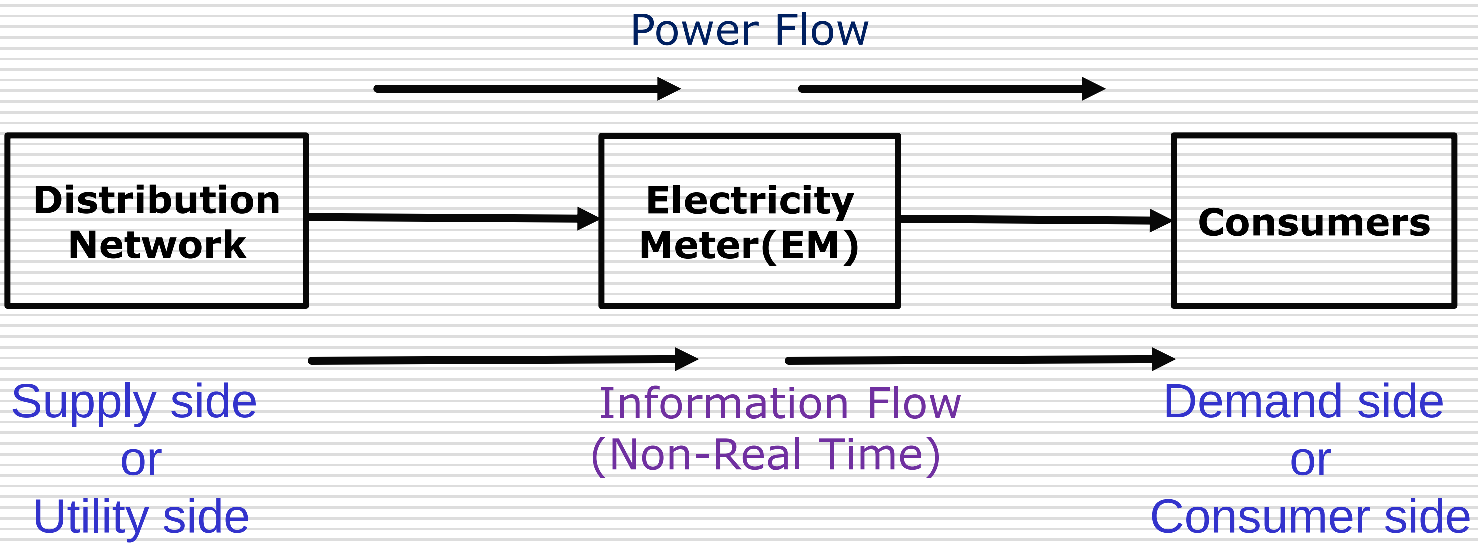
Traditional Power/Energy Distribution System

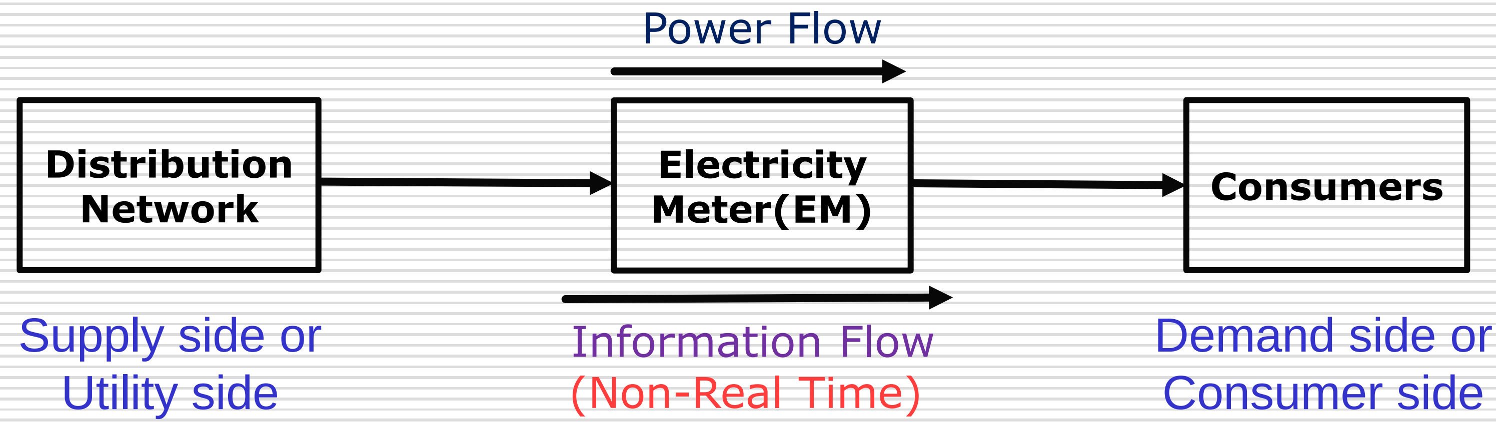


Smart Distribution : Concept

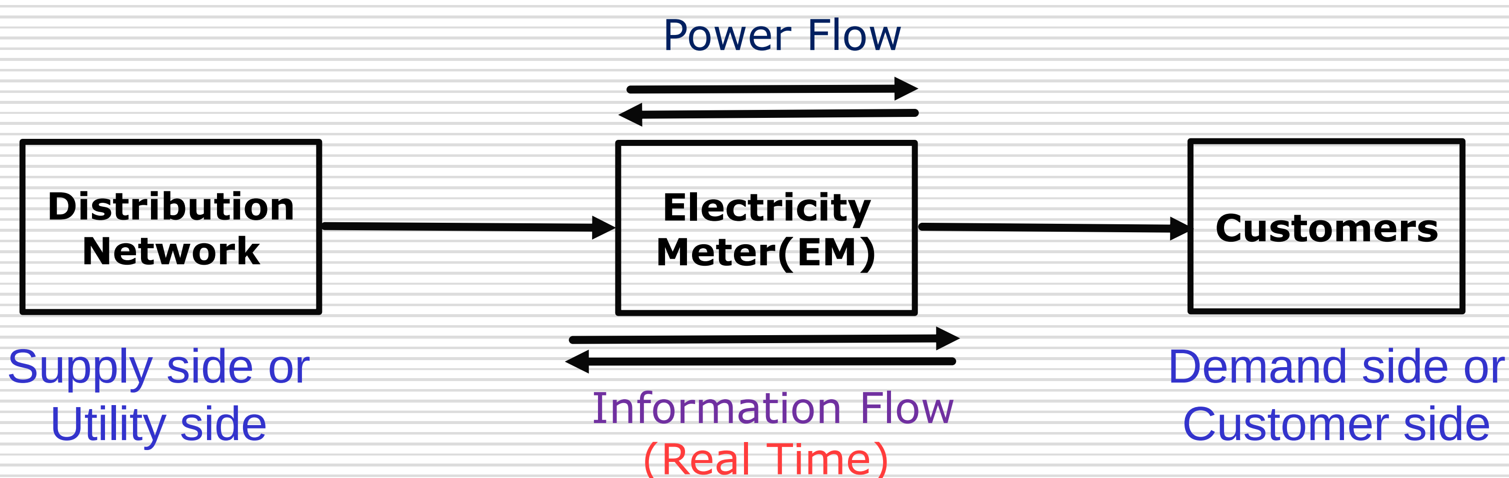
- Like Smart Grid, Smart Distribution is also a concept.
- The concept of smart distribution consists basically in integrating the demand side resources with the utility side resources.
- The concept is also known as demand side integration (DSI).
- Smart distribution is characterized by the following features:
  i. Two-way power flow between the utility and the customers, specially the bulk customers.
  ii. Two-way real-time flow of information between the utility and the customers.
  iii. Active participation by the customers.
- The term “customers” in smart distribution includes the Following:
  a) Bulk consumers,
  b) Secondary distribution companies, and
  c) Electricity traders.

Traditional versus Smart Distribution

❑ Traditional Distribution



❑ Smart Distribution



Utility-Side Resources

a) Distribution transformers
b) Feeders
c) Switchgear
d) Protection gear

e) Distributed generation (optional)
f) Energy storage (optional)

Demand-Side Resources

a) Flexible load
b) Power factor control

c) Distributed generation (optional)
d) Energy storage (optional)
e) Plug-in electric vehicles (optional)

Objectives of Smart Distribution or DSI

a) Supporting the operation and management of the power supply system
b) Improving quality of power supplied to the consumers
c) Reducing the electricity bill of the customers participating in DSI.

Requirements of DSI (DSI Enablers)

- Following are the essential requirements of demand side integration:
  a) There have to be incentives from the utility to its consumers.
  b) Consumers should have desire and means to participate (also called as “demand side participation”).
  c) Two-way real-time communication between the utility and the customers.
- Also called as the **DSI Enablers**.

Demand Side Management (DSM)

- Smart distribution or demand side integration (DSI) is largely based on demand side management.
- Demand side management (DSM) means all the activities carried out, or the measures taken, on the demand side (that is, the customer side) of an energy system.
- While DSM was initially “utility-driven”, it is gradually moving towards a “customer-driven” activity.
- DSM should preferably be driven jointly by the utility and the customer for following reasons:
  a) Both parties stand to gain from DSI.
  b) Any action on either side affects both sides of the energy system.

Activities or Components of DSM

1. Energy efficiency (EE) measures.
2. Energy conservation (EC) measures.
3. Incentive-based tariffs
4. Dynamic pricing
5. Demand response (DR)
6. Virtual spinning reserve (VSR)
7. Two-way high-speed digital communication among the utility and customers (to enable coordinated operation of the energy system).

DSM Categorization

- DSM has been categorized on the basis of the nature of the activity into (a) Permanent DSM, and (b) Dynamic DSM.
- **Permanent DSM means** a management action that has a permanent (long-lasting) effect on the energy system.
- **Permanent DSM includes** the following measures:
  a) Energy efficiency (EE) measures
  b) Energy conservation (EC) measures
- **Dynamic DSM means** a management action that has a short-term effect.
- **Dynamic DSM includes** the following measures:
  a) Incentive-based tariffs
  b) Dynamic pricing
  c) Demand response (DR)
  d) Virtual spinning reserve (VSR)
  e) Two-way high-speed digital communication.

1 - Energy Efficiency (EE) Measures

- These are the measures by which efficiency of energy utilization on the demand side can be increased.
- The measures have to be taken essentially by the consumers.
- The measures will have a permanent (long-lasting) effect on reducing both, the energy consumption and the peak demand, of the consumer and thus reduce his electricity bill.
- Energy efficiency can be increased by taking two types of measures:

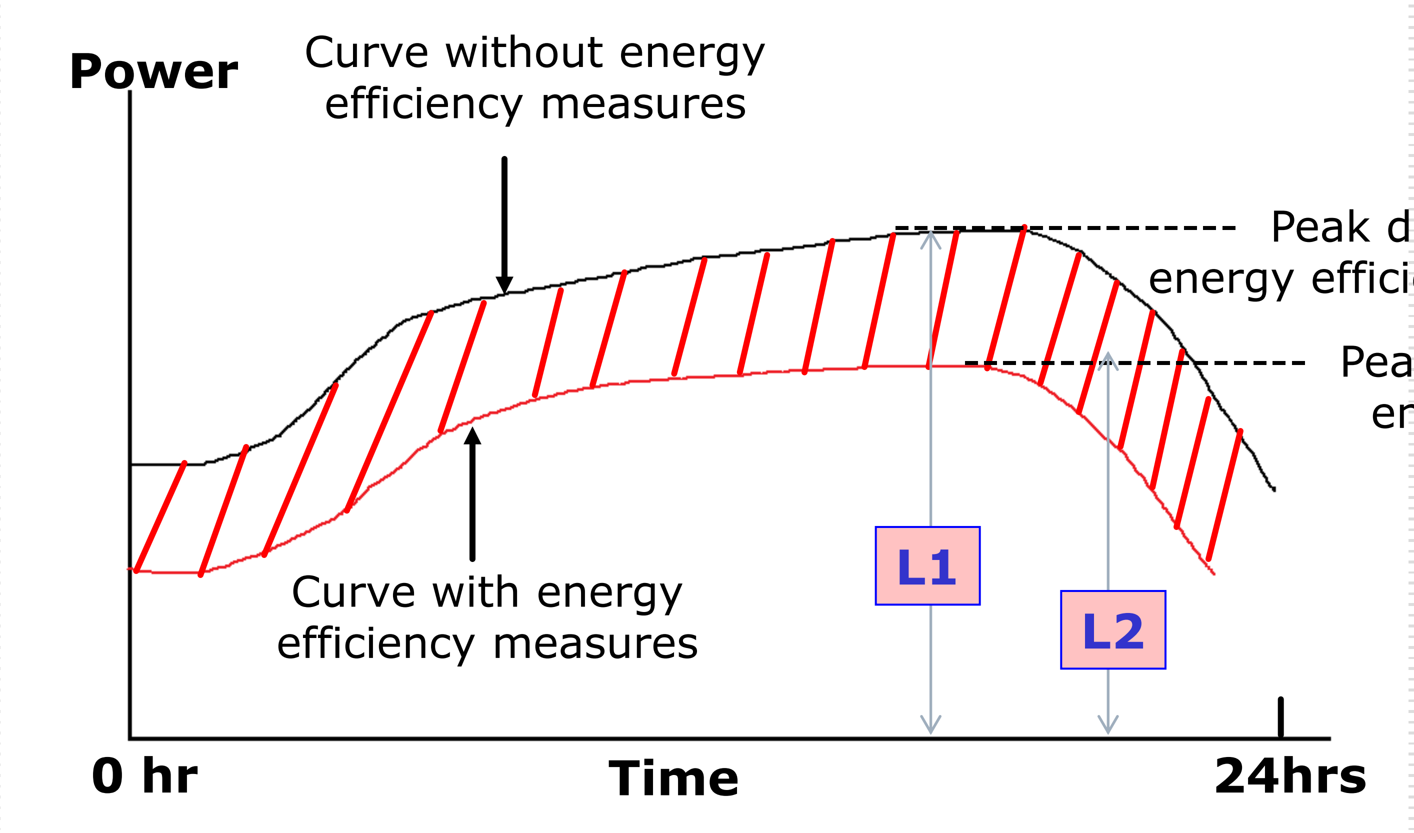
a) Use of energy-efficient equipment, such as:

I. Use of CFLs instead of incandescent lamps
II. Use of LED lamps instead of CFLs
III. Use of motors and pumps of higher efficiency
IV. Use of air-conditioners and refrigerators of higher efficiency

b) Use of energy-efficient systems; for example:

I. Prevent frequent opening of doors of an air-conditioned room.
II. Prevent overflow of water from overhead water tanks.

Effect of Energy Efficiency Measures



Effect 1: Reduction in energy consumption (shown by red shaded area)

Effect 2 : Reduction in peak demand (difference between L1 and L2)

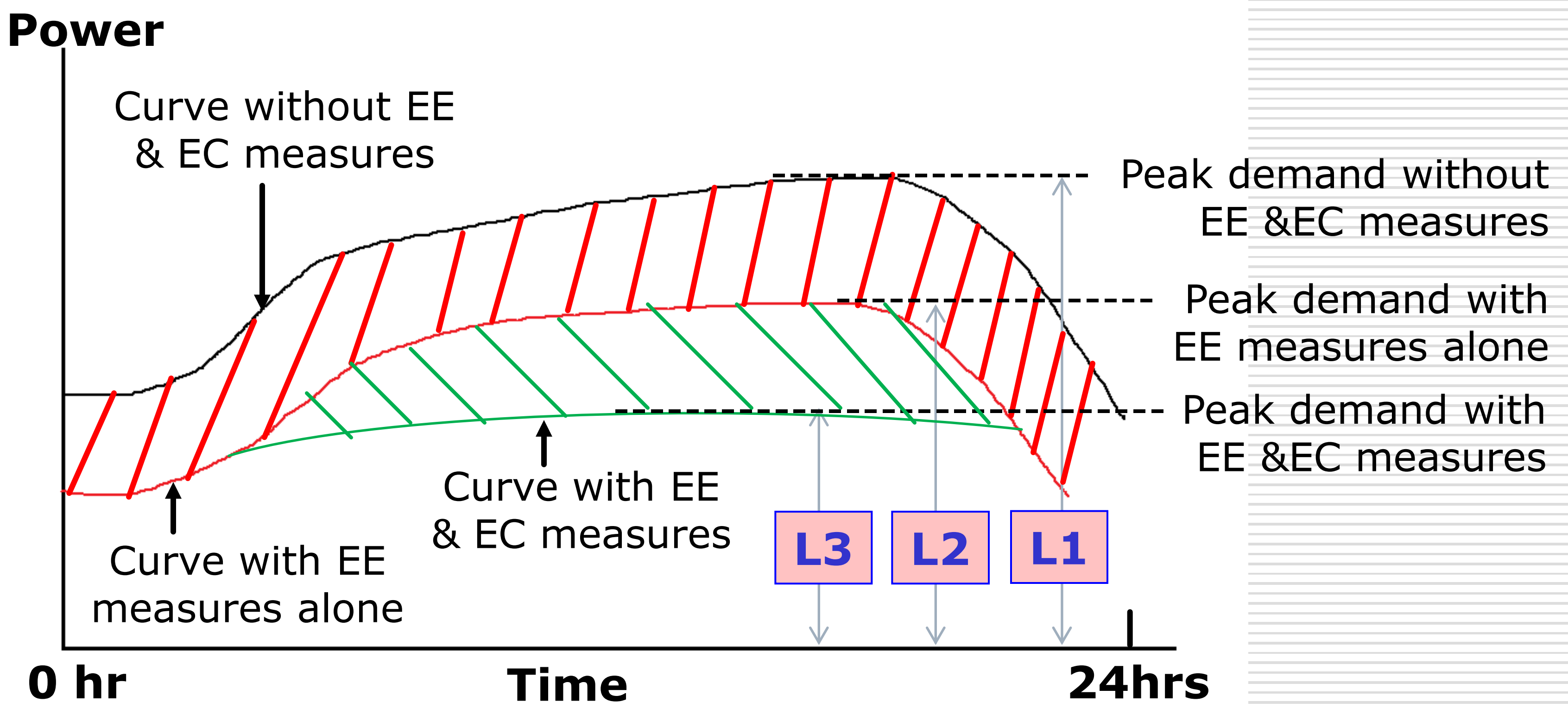
2 - Energy Conservation (EC) Measures

- Energy Conservation measures include all long-term actions that can conserve energy in any possible way.
- Like EE measures, the EC measures have to be taken by the consumer essentially.
- Like EE measures, the EC measures will also have a permanent (long-lasting) effect on reducing both, the energy consumption and the peak demand, of the consumer and thus reduce his electricity bill further.
- Energy can be conserved by taking two types of measures:
  - a) Behavioral changes in the electricity users so as not to waste electricity.
  - b) Sensor-based automatic control of loads.

Sensor-Based Automatic Control of Loads

- Two types of sensor-based control:
  a) **On-off control:** For example, switching on and off lights, fans, air-conditioner, dehumidifier etc.
  b) **Modulation or Regulation**: For example, dimming of lights, speed control of a fan, variable-flow air conditioner, etc.
- Commonly used sensors in automatic control of loads:
  a) Occupancy sensors
  b) Motion sensors
  c) Day-light sensors
  d) Temperature sensors
  e) Humidity sensors
  f) CO_2 sensors
  g) Timers.

Effect of Energy Conservation Measures



Effect 1: Reduction in energy consumption (shown by green shaded area)

Effect 2 : Reduction in peak demand (difference between L2 and L3)

3 - Incentive-Based Electricity Tariffs

- Special tariffs are floated by utilities with the objective of encouraging (giving incentive for) participation of consumers in DSM.
- These tariffs are valid for a long term, such as three, six or 12 months, so that the customers can do **long-term planning** to take full advantage.
- Two types of tariffs are generally used for this purpose:
  a) Two-part tariff
  b) Time-of-use or ToU tariff.

Two-Part Tariff

- Two-part tariff has two components of billing:
  - **Part A**: Bill for energy used in kWh, and specified as Rs. 'x' per kWh of energy consumed.
  - **Part B**: Bill for the maximum or peak demand over the billing period, and specified as Rs. 'y' per kVA of peak demand.
- Total bill = Part A + Part B

  = (x·energy in kWh) + (y·peak demand in kVA)
- Part B gives incentive to customers to undertake following steps:
  - Reduce their peak demand in terms of active power using EE and EC measures, and
  - Improve their power factor by installing capacitor banks.

Time-of-Use (ToU) Tariff

- In this case, the tariff or rate offered by the utility varies with the time of use of electricity by the consumers.
- The tariff is:
  a) different for different times of the day, and/or
  b) different for different seasons.
- The tariff is so designed by the utility that customers make efforts to reduce their bill by managing their resources (the demand-side resources, mentioned in an earlier slide).
- For example, shifting some of the flexible loads from the peak-load time (when the tariff is high) to off-peak time (when the tariff is low), or storing electricity in energy storage devices when tariff is low and withdrawing the same when tariff is high.
- The tariff thus helps to reduce the maximum demand on the utility as a whole.
- The utility can thus make best use of its infrastructure.

4 - Dynamic Pricing of Electricity

- Two types of dynamic pricing of electricity can be expected:
  a) Daily pricing
  b) Real-time pricing.
- **Daily Pricing:** Prices of electricity can be changed by the utility on daily basis as per electricity-market conditions.
  - The prices would be informed to customers and would be valid for the next day.
  - The customers can do **short-term planning** or **daily planning** in response to daily prices, and manage their flexible loads accordingly.
- **Real-Time Pricing:** Prices of electricity can change at any time in case of a major failure (of large generators, transformers etc.) and/or outage of power supply in an area.
  - Affected customers would be informed of the change in the prices.
  - These customers can suitably respond by managing their resources (the demand-side resources).

5 - Demand Response: What is it?

- Demand response or DR means “response of the customers (i.e. the demand side of the energy system) to: (a) incentive-based tariffs, (b) electricity market or (c) state of the power grid”.
- Accordingly, the demand response can be of following three types:
  a) Tariff-driven DR
  b) Market-driven DR
  c) Grid-state-driven DR or physical DR.
- The response may consist in managing the following customer-side (or demand-side) resources in the most appropriate way:
  i. Flexible load
  ii. Power factor control
  iii. Distributed generation
  iv. Energy storage
  v. Plug-in electric vehicles
- DR on the whole is expected to mutually benefit the customers and utility.

5a - Tariff-Driven DR

- This type of demand-side response is essentially to the two types of incentive-based tariffs described earlier, namely
  a) Two-part tariff
  b) Time-of-use or ToU tariff.
- **The response to two-part tariff** would generally consist in the following actions on the demand side:
  - Using energy efficiency and energy conservation measures to reduce the total energy consumption and the peak demand.
  - Improving power factor to reduce peak demand in kVA.
- **The response to time-of-use tariff** would generally consist in the following actions on the demand side:
  - Shifting some of the flexible loads (like washing machines, water heaters, etc.) from the peak-load time (when the tariff is high) to off-peak time (when the tariff is low).
  - Storing electricity in energy storage devices when tariff is low and withdrawing the same when tariff is high.
  - Charging plug-in electric vehicles when tariff is low, typically during the night.

5b - Market-Driven DR

- This type of demand-side response relies on certain market places where electricity is traded and prices change dynamically on the basis of demand-supply position of electricity.
- These markets decide two types of prices that change dynamically (as described earlier), namely
  a) Daily prices
  b) Real–time prices.
- **In response to the daily prices**, the customers can do planning on day-to-day basis so as to manage their flexible loads to reduce their electricity bill.
- **The response to real-time prices** has to be spontaneous, which may include manipulating flexible loads and energy storage devices.

5c - Grid-State-Driven DR or Physical DR

- The power grid operates in three states:
  a) Normal grid operation
  b) Maintenance of some component or equipment of the grid
  c) Failure of a part or component of the grid.
- In the event of ongoing maintenance or failure of some major component, the availability of power in some area would reduce. So the utility sends a request to customers in that area participating in DSI to reduce their demand for a certain period.
- The request is binding on these customers.
- The response of the customers to such requests is called as **grid-state driven DR or operation-driven DR or physical DR.**
- The customer responds by reducing his demand temporarily for that period using his resources (the demand side resources).

6 – Spinning Reserve

- Spinning reserve is a reserve of power, which can respond instantly to an unbalance between the demand and supply arising abruptly in a power system/grid.
- The unbalance can arise due to sudden rise or fall in the demand (load) or sudden failure of a generating unit in the system.
- The spinning reserve can be:

a) **Real or conventional spinning reserve:** used in traditional power grid.

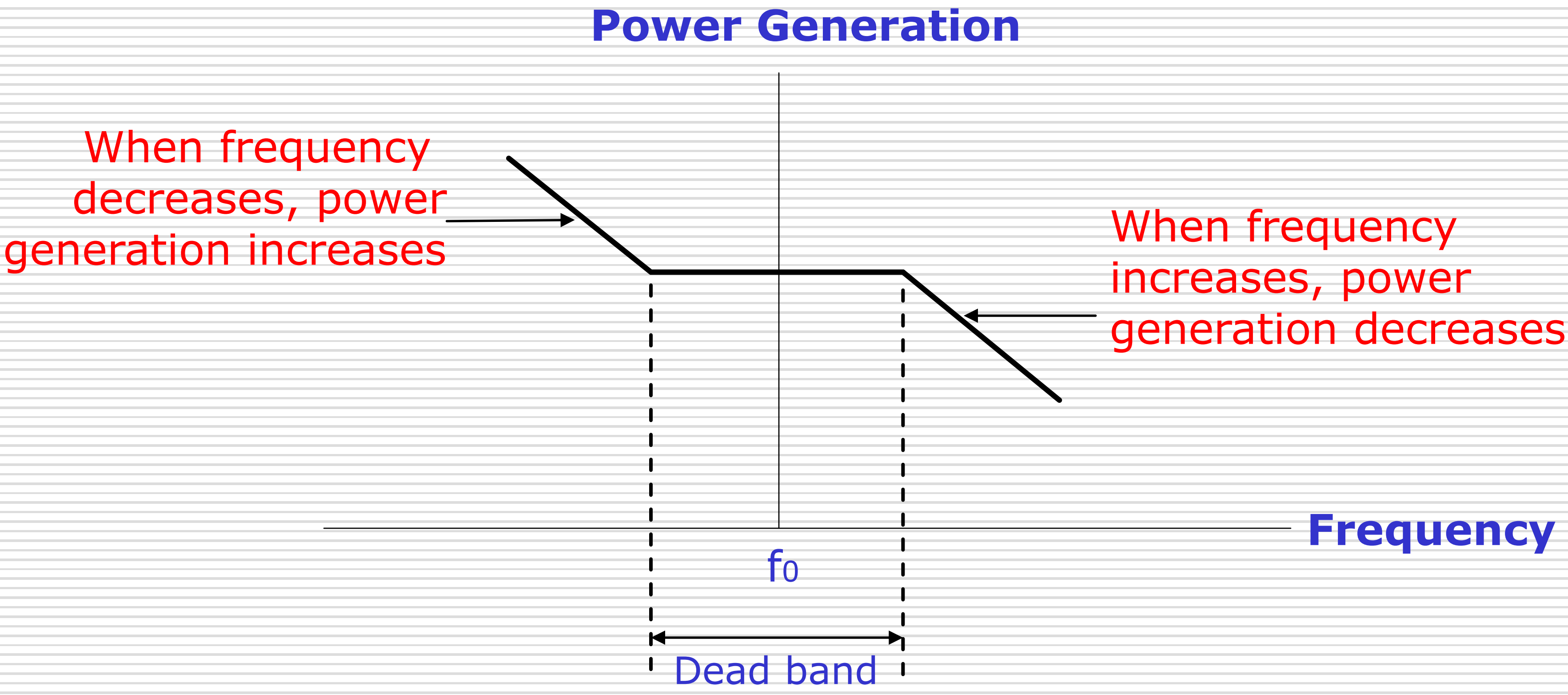
b) **Virtual spinning reserve:** the concept used for demand side management in a smart grid.

6a– Real or Conventional Spinning Reserve

- In a traditional power grid, the frequency of the system is maintained constant at the desired value (50 Hz for Indian power grid) with the help of a **regulating power plant**.
- A large generating unit in this plant is kept running on no load or a light load (the condition is called **"spinning**").
- If the system frequency tends to go down because of an additional power demand on the system, this unit raises its output power instantly. Thus this spinning generating unit acts as an ever-ready power reserve. Hence called as **"spinning reserve".**
- In case the system frequency tends to rise because of an abrupt fall in the power demand on the system, this very unit would reduce its power output instantly.
- The response of a Real or Conventional Spinning Reserve is shown in the next slide.

Response of Real Spinning Reserve

- A dead band is provided around the desired frequency setting, f_0.
- No action is initiated by the spinning reserve (generating unit) as long system frequency is within the dead band.

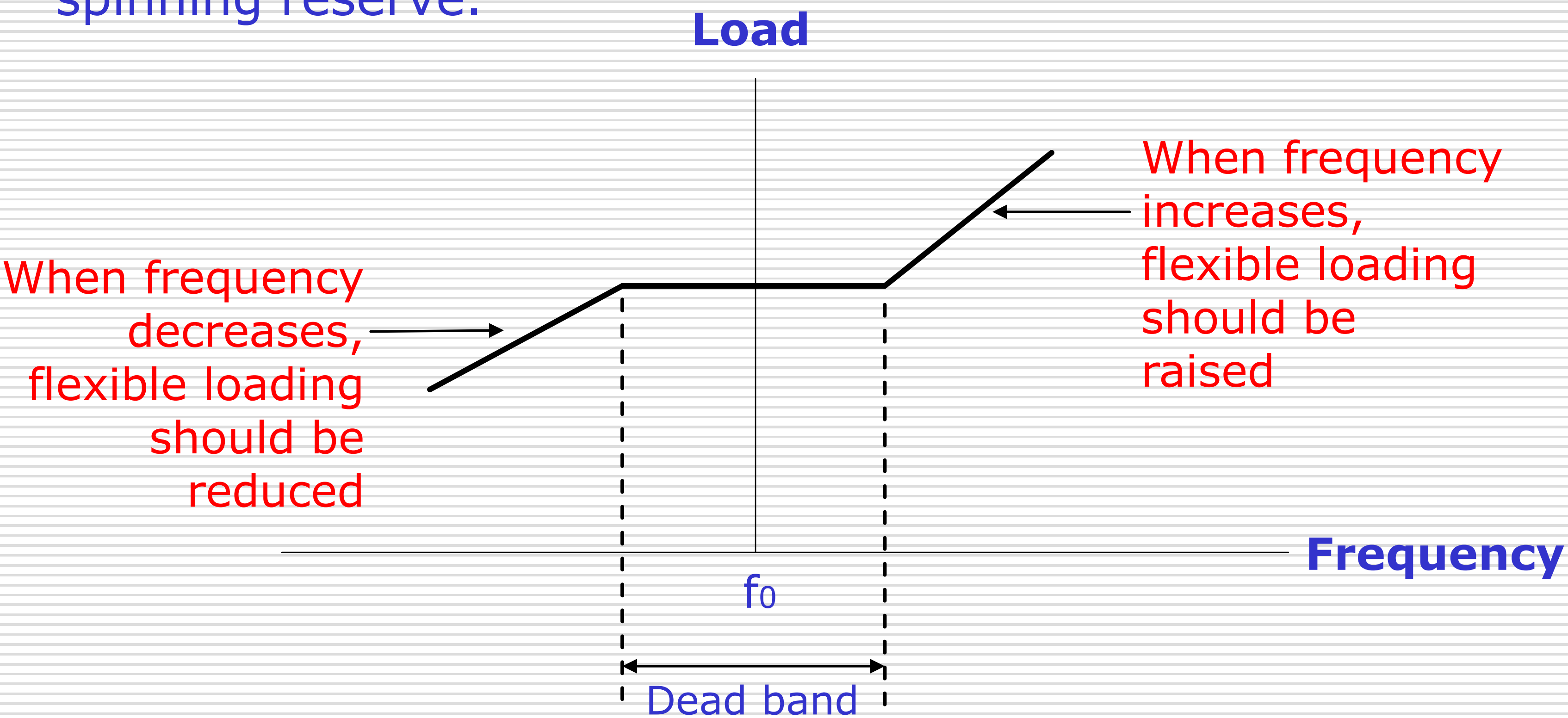


6b– Virtual or Negative Spinning Reserve

- In a smart grid, **the flexible loads on the demand side** (that is, the distributed flexible loads of the consumer) can **virtually** be used as a **negative spinning reserve**.
- These loads would have a reverse effect on the system frequency relative to the real spinning reserve, which is a generating unit.
- If the system frequency falls below the setting value (due to an abrupt increase in the demand or an abrupt failure of a generating unit or station), the flexible loads should be **instantly reduced** to help the power system recover.
- Similarly, in case the system frequency tends to rise (because of an abrupt fall in the power demand on the system), the flexible loading should be instantly increased.
- Thus, the flexible loads can respond instantly like a spinning generating unit, but in reality they are not a spinning reserve of power generation. Hence called as **"virtual spinning reserve".**
- The response of virtual spinning reserve is shown in the next slide.

Response of Virtual Spinning Reserve

- A dead band has to be provided around the desired frequency setting, f_0, in this case also.
- Small variations in system frequency within the dead band do not call for any correction by using either real or virtual spinning reserve.



Distributed Energy Resources (DERs)

- An important and fast upcoming feature of smart distribution is the addition of distributed energy resources (DERs).
- Distributed energy resources comprise two types of energy resources:
  - a) Distributed Energy Generation (DG)
  - b) Distributed Energy Storage (ES)
- These resources may be located and connected at:
  - The customer level, i.e. on the demand side of the energy system, and/or
  - Distribution level, i.e. on the utility side of the energy system.

Distributed Generation (DG)

- Distributed energy generation, or distributed generation, or DG, means that power is generated using **small** power generation units or plants **distributed** in a power/energy system and connected near major load points in the system.
- DG can be located and connected on the customer (demand) side and/or the utility side of the system.
- Capacity of the power generation units or plants is usually less than 10 MW, although larger units are sometimes used.
- DG includes power generation from a variety of **renewable energy resources**, preferably **green energy resources**.
- Depending upon their local availability, DG in a particular energy system may include one or more of the following:
  - Solar PV power
  - Small hydro power
  - Wind power
  - Fuel cells
  - Micro-turbines
  - Geo-thermal power
  - Tidal power
  - Wave power

Benefits of Distributed Generation

1. Reduction in power generation capacity required of central power generating plants.
2. Reduction in power flow through transmission and distribution systems, as the DERs are generally located near the load points.
3. Reduction in transmission and distribution losses, so efficiency of the system is improved.
4. Improved power quality in terms of voltage fluctuations and interruptions, as the generating units are located and connected close to the loads.
5. Better voltage and reactive power control due to the closeness of loads and generating units.
6. As the distributed energy generation is usually done from green energy sources, there are no (or negligible) carbon emissions. Hence greener environment.

Need of Distributed Energy Storage (ES)

- Electrical energy has a special characteristic the power generation has to match the load demand at all times.
- So if there is a need to store electrical energy at one time so as to use it later, it should be converted to some other form of energy in which it could be conveniently stored.
- As mentioned earlier, DG is generally made from renewable energy sources (also listed earlier), most of which are intermittent in nature. Very frequently. the power generation does not match with the load demand.
- Two alternative solutions are possible and used:
  a) Use DG along with power from the main grid
  b) Use distributed energy storage devices
- Energy storage can be defined as the conversion of electrical energy (from a power system) into another form, in which it can be stored, and its conversion back to electrical energy when required.

Energy Storage Techniques and Systems

- Energy storage can be defined as the conversion of electrical energy (from a power system) into another form, in which it can be stored, and its conversion back to electrical energy when required.

S. No.	Technique/ Principle	Energy Storage System
1	Hydraulic	Pumped storage system
2	Fluidic	Compressed air
3	Electrical	(a) Double-layer capacitor (b) Super-conducting magnetic coil
4	Mechanical	Fly-wheel
5	Thermal	Heat storage system
6	Electro-chemical	Rechargeable (or secondary) batteries

- The most common energy storage device used in smart distribution is the rechargeable or secondary batteries.

Secondary Batteries for ES

- A secondary or rechargeable battery stores energy through a reversible electro-chemical reaction.
- During charging, electrical energy is used in causing forward reaction, while electrical energy is produced by the reverse reaction during discharging.
- Important types of rechargeable batteries:

Lead acid battery : Oldest type, most commonly used.

Adv: (a) Works at room temperature; (b) Low cost.; (c) Can deliver surge currents (high power for short time).

Disadv: (a) Low energy density (i.e. large size); (b) Short life.

Secondary Batteries for ES (contd.)

- **Nickel-Cadmium (Ni-Cd) battery :** Not popular now.

  Adv: (a) Robust; (b) High energy density (i.e. compact battery); (c) Maintenance free.

  Disadv: (a) Costly; (b) Cadmium is a toxic material..

- **Nickel-Metal Hydride (Ni-MH) battery :** Uses a hydrogen-absorbing alloy in place of toxic cadmium for negative electrode. Becoming popular now.

  Adv: (a) Robust; (b) High energy density (i.e. compact battery); (c) Maintenance free.

  Disadv: Costly.

- **Lithium-ion(Li-ion) battery :** Becoming popular now.

  Adv: (a) Robust; (b) Highest energy density (i.e. most compact type battery); (c) Maintenance free.

  Disadv: Costly.

Advantages of Distributed Energy Storage

1. Allows to use full potential of renewable energy resources.
2. Helps to improve power quality.
3. Helps consumers to suitably shift the time of use of electricity to take advantage of time-of-use tariffs.
4. Energy storage may be used as spinning reserve.
5. Distribution lines can be relieved of power congestion by installing energy storage devices close to the loads, specially the peaky loads.

Plug-in Electric Vehicles (PEVs)

- Electric vehicles are of two types depending on the source of electrical power needed by the motor:
  a) **Battery electric vehicle (BEV),** which takes electrical power from on-board rechargeable (secondary) batteries.
  b) **Fuel-cell electric vehicle (FCEV),** which takes electrical power from on-board fuel cells.
- In a battery electric vehicle, the batteries arte recharged by plugging into either an AC power outlet or a DC charging station. Hence, these are called **"plug-in electric vehicles"**.
- Plug-in electric vehicles (PEVs) are of two types depending on the source of power:
  A. **Plug-in battery electric vehicle (PBEV),** for which the source of power is batteries exclusively.
  B. **Plug-in hybrid electric vehicle (PHEV),** for which the source of power is a hybrid (combination) of batteries and an IC engine.

Plug-in Battery Electric Vehicle (PBEV)

- The vehicle has only an electric motor and no internal-combustion (IC) engine.
- It runs exclusively on the on-board rechargeable batteries.
- The on-board batteries are recharged by plugging into either an AC power outlet or a DC charging station
- In the former case, the vehicle must have an on-board charger for the batteries.
- There are no carbon emissions from the vehicle.
- The vehicle range is limited by the size and condition of the batteries.

Plug-in Hybrid Electric Vehicle (PHEV)

- The vehicle is equipped with both, rechargeable batteries and an internal-combustion (IC) engine that drives an electric generator.
- During a journey, the motor is run from the on-board batteries as long as the batteries last. After that the IC engine is started, which then recharges the batteries through the generator.
- After the journey is over, the batteries are recharged by plugging into either an AC power outlet or a DC charging station just like a PBEV.
- There are carbon emissions from the vehicle when IC engine runs, just like an IC engine-powered non-electric vehicle..
- The vehicle range is not limited by the size of the batteries.

Benefits of PEVs

1. No pollution on road in case of PBEVs and less pollution on road by PHEVs as compared to that by IC-engine driven (conventional) vehicles.
2. The cost of running of a PEV on batteries is typically 3 to 4 times lower than that of IC-engine driven (conventional) vehicles.
3. PEVs supports demand response in two ways:
   a) PEV can serve as a flexible load, as the batteries of the PEV can be charged when tariff is low.
   b) Batteries of PEVs can serve as spinning reserve.

Challenges/Problems of PEVs

1. Battery charging stations need to be set up in towns and cities and along high-ways.
2. Power demand on power systems/ power grid will go up, which will require strengthening of their infrastructure in terms of generation, transmission and distribution of power.
3. The time required for recharging batteries of a PEV is much longer than the time required to refill the fuel tank of an IC-engine driven vehicle.
4. Motor garages will have to be equipped to handle repair and maintenance of PEVs, specially the maintenance and replacement of rechargeable batteries of PEVs.
5. Technicians of motor garages will need to be re-trained to handle repair and maintenance of PEVs.

