U.S.-PAKISTAN CENTER
FOR ADVANCED STUDIES
IN ENERGY (USPCAS-E)

Smart Grid Architecture
ESE-909 (Core)
Lecture 2
(Basics of SG based Communication & Measurement)

By

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Communications & Measurement Technology in SG

1. Communications and Measurement Technology

2. Monitoring, PMU, Smart Meters, and Measurements Technologies (MPSM)

3. GIS and Google Mapping Tools

3.5 Demand Side Integration

4. Multi-agent Systems (MAS) Technology

5. Micro-grid and Smart Grid Comparison

Smart Grid

Question

Answer

What is Smart Grid??

Smart Grid

=

Information & Communication Technologies (ICT)

+

Electric Grid Modernization

+

Asset Optimization

+

Integration of New Emerging Concepts

Obviously, existing measuring, monitoring, and control technology will have a role in SG capability. Establishing appropriate standards, cyber security, and interoperability requires careful study.

1. **Standards and protocols for the secure transmission of info.**
2. **Plug and play based architecture.**

Communication Technologies and 5 characteristics of SG Communication

1. <u>Multiprotocol Label Switching (MPLS)</u>: High - performance telecomm networks for data transmission between network nodes
2. <u>Worldwide Interoperability for Microwave Access (WiMax):</u>Wireless telecommunication technology for point to multipoint data transmission utilizing Internet technology
3. <u>Broadband over Power Lines (BPL): </u>Power line communication with Internet access
4. <u>Wi - Fi: </u>Commonly used wireless local area network (LAN)

<u>Additional Communication Technologies:</u>

1. Optical Fiber/Fiber optic (FO)
2. Mesh
3. Multi-point Spread Spectrum

<u>5 Key Characteristics of SG Communication</u>

1. High bandwidth.
2. IPv6 - enabled digital comm.
3. Encryption
4. Cyber Security
5. Support and quality of service and Voice over Internet Protocol (VoIP).

Local Area Network

- **Def**. A computer network that links devices (nodes), which follow common rules, within a building or set of buildings, encapsulating a radius of less than 1-10 km. Examples in SGs include SHs, SBs and SNHs.

- LAN is a shared access technology, means all of the attached devices shares a common communication medium like coaxial, twisted pair, fiber optics cable.

Network Interface Card (NIC):

1. Connects to Network
2. A physical Connection Card

Network Software

Manages Comm among system & stations.

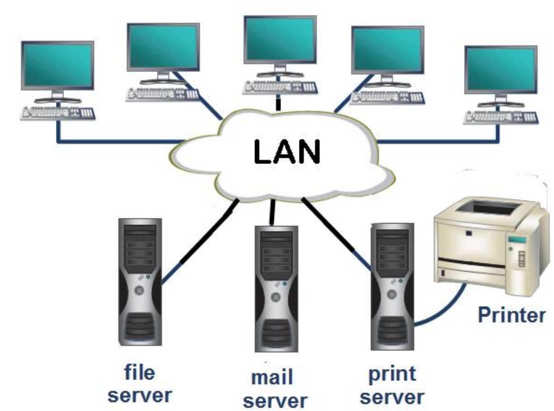


Fig. A Simple Diagram of Local Area Network

Attributes and Advantages of LAN

1. **Recourse Sharing:** A printer is shared by all.
2. **Areas Covered:** Small e.g. university, office.
3. **Cost and availability:** Affordable/Off the shelf.
4. **High channel Speed:** Transfer data rate@ 1-10Mbps.
5. **Flexibility:** Easy to maintain and operate.

Three categories of data transmission in LAN:

1. **Unicast transmission:** Single data packet from source to address.

2. **Multicast transmission:** Single data packet is copied and sent to a specific subset of nodes (using multicast addresses) on network. E.g. Forms.

3. **Broadcast transmission:** a single data packet is copied and sent to all nodes on the network; the source node addresses the packet by using the broadcast address. E.g. Circular in office.

LAN Topologies (How devices are organized?)

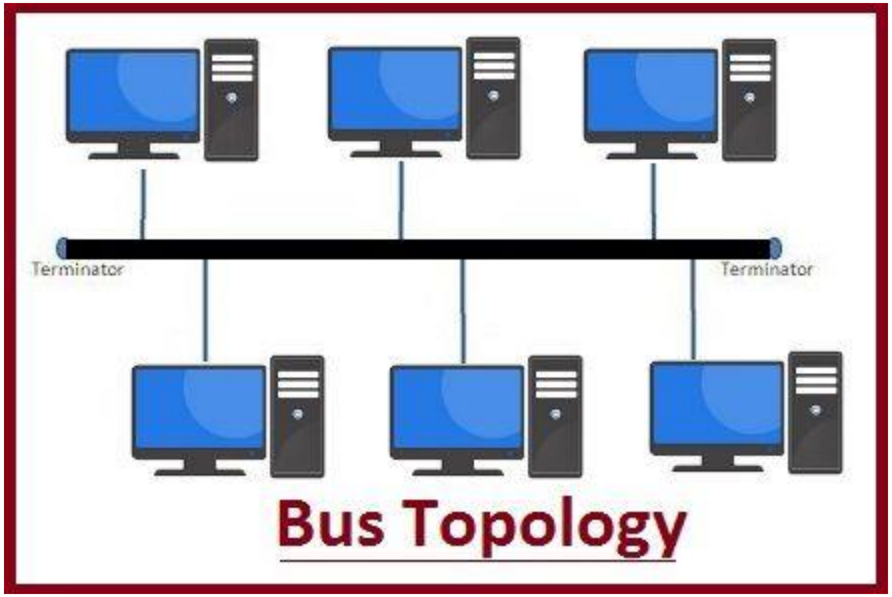
1. Bus topology: Linear LAN architecture in which transmission from network station propagates the length of the medium and is received by all other stations connected to it.

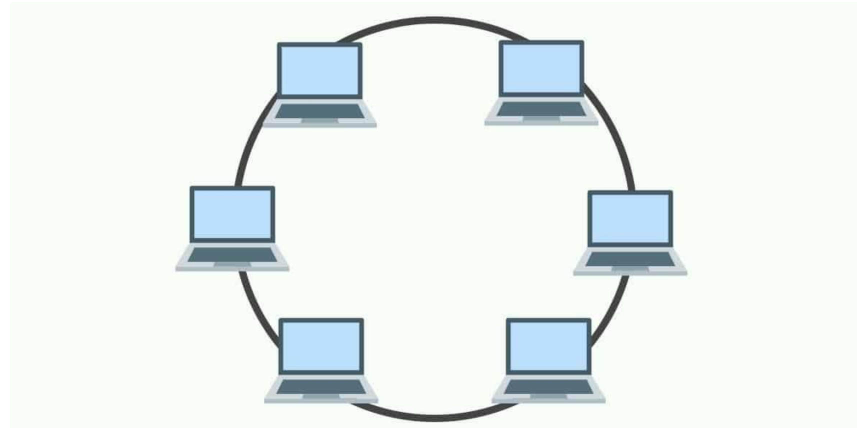
2. Ring bus topology: A series of devices coupled to one another by unidirectional transmission links to form a single closed loop

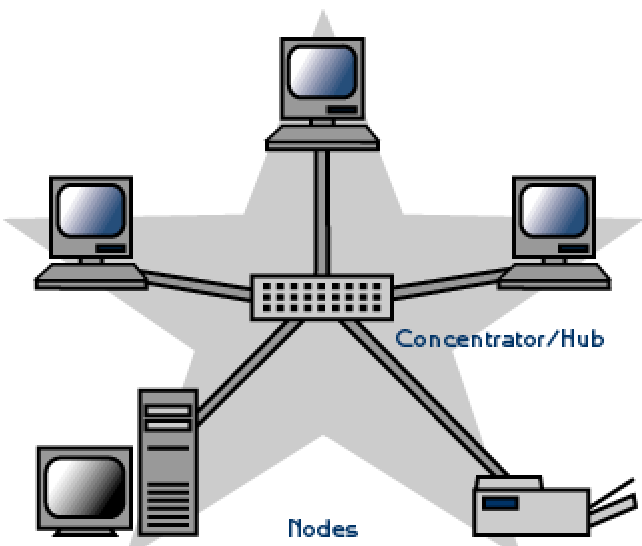
3. Star topology: the end points on a network are connected to a common central hub or switch by dedicated links

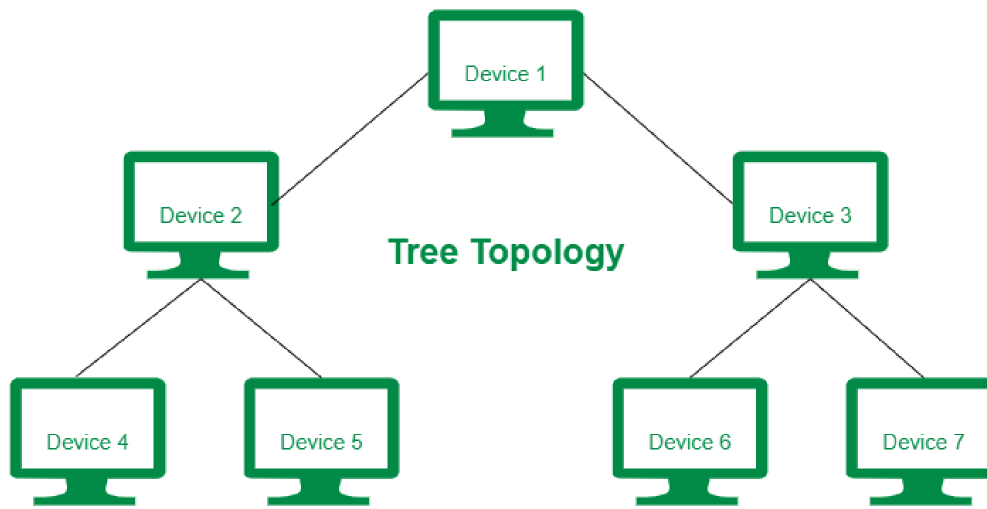
4. Tree topology: identical to the bus topology except that branches with multiple nodes are also possible

Note: The devices and software used in LAN utilize a standard protocol such as **Ethernet/ IEEE 802.3**, **Token Ring/IEEE 802.5 or 880.2**


Terminator
Terminator
Bus Topology




Concentrator/Hub
Nodes


Device 1
Device 2
Tree Topology
Device 3
Device 4
Device 5
Device 6
Device 7

Other related networks

- **<u>Home Access Network (HAN)</u>:** It is a LAN confined to an individual home.
  - It enables remote control of automated digital devices and appliances throughout the house.
  - Smart meters, smart appliances and Web-based monitoring can be integrated into this level.

- **<u>Neighborhood Area Network (NAN)</u>:** Ideally, it will cover an area larger than a LAN.
  - It is a wireless community currently used for wireless local distribution applications.

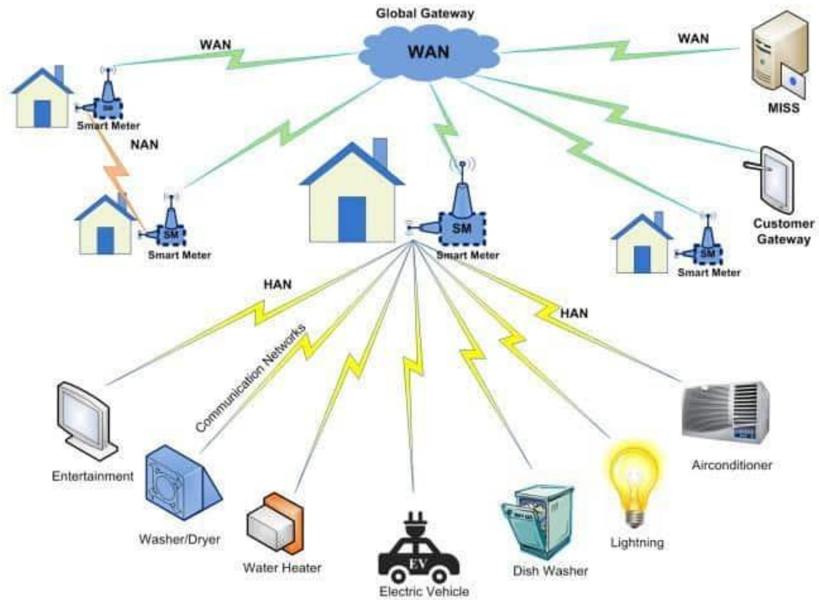


Fig: Wide Area Network (WAN)

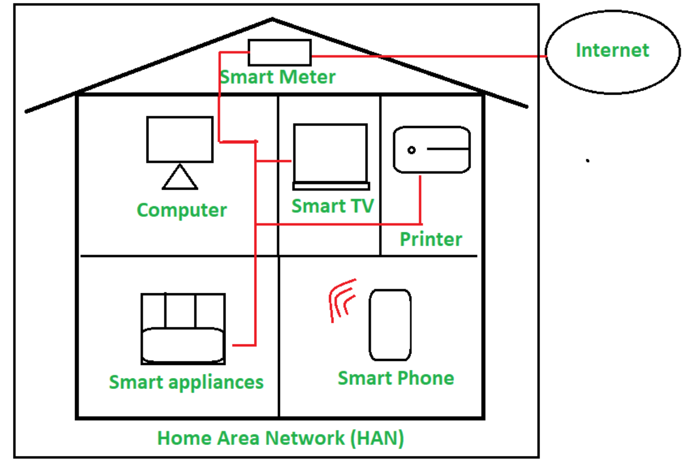


Fig: Home Area Network (HAN)

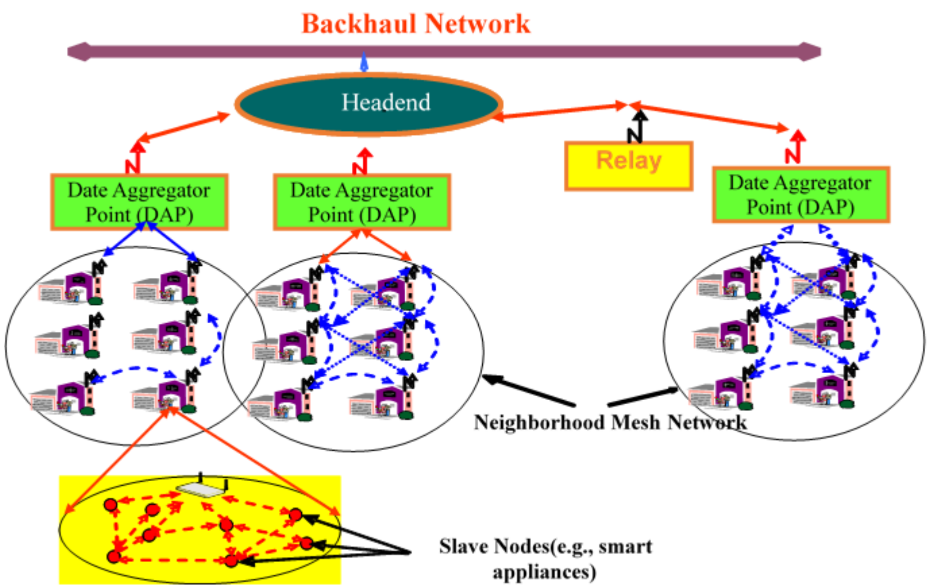


Fig: Neighborhood Area Network (NAN)

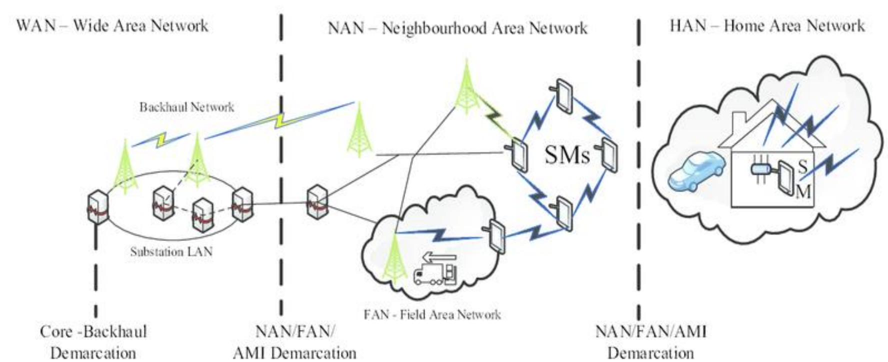


Fig: Network Domains from LAN to WAN

Communication within NIST Domains

1. **Bulk generation: includes** market services interface, plant control system, and generators; <u>this domain interacts</u> with the <u>market operations and transmission domains</u> **through** wide area networks, substation LANs, and the Internet

2. **Transmission :** includes substation devices and controllers, data collectors, and electric storage; <u>this domain interacts</u> with <u>bulk generation and operations</u> **through** WANs and substation LANs; integrated with the distribution domain

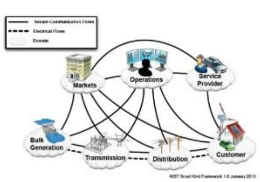
3. **Distribution:** this domain <u>interacts with operations and customers</u> **through** Field Area Networks

4. **Customer: includes** customer equipment, metering, Energy Management Systems (EMS), (DSM), electric storage, appliances, PHEVs, and so on

5. **Service Providers: includes** utility and third party providers which handle billing customer services, and so on; this domain <u>interacts with operations and customers</u> primarily through the Internet

6. **Operations: includes** EMS, Web Access Management System (WAMS), and SCADA; this domain can be sub - divided into ISO (independent system operator) /RTO (regional transmission organization), transmission, and distribution

7. **Market: includes** ISOs/RTOs, aggregators, and other market participants



NIST Framework

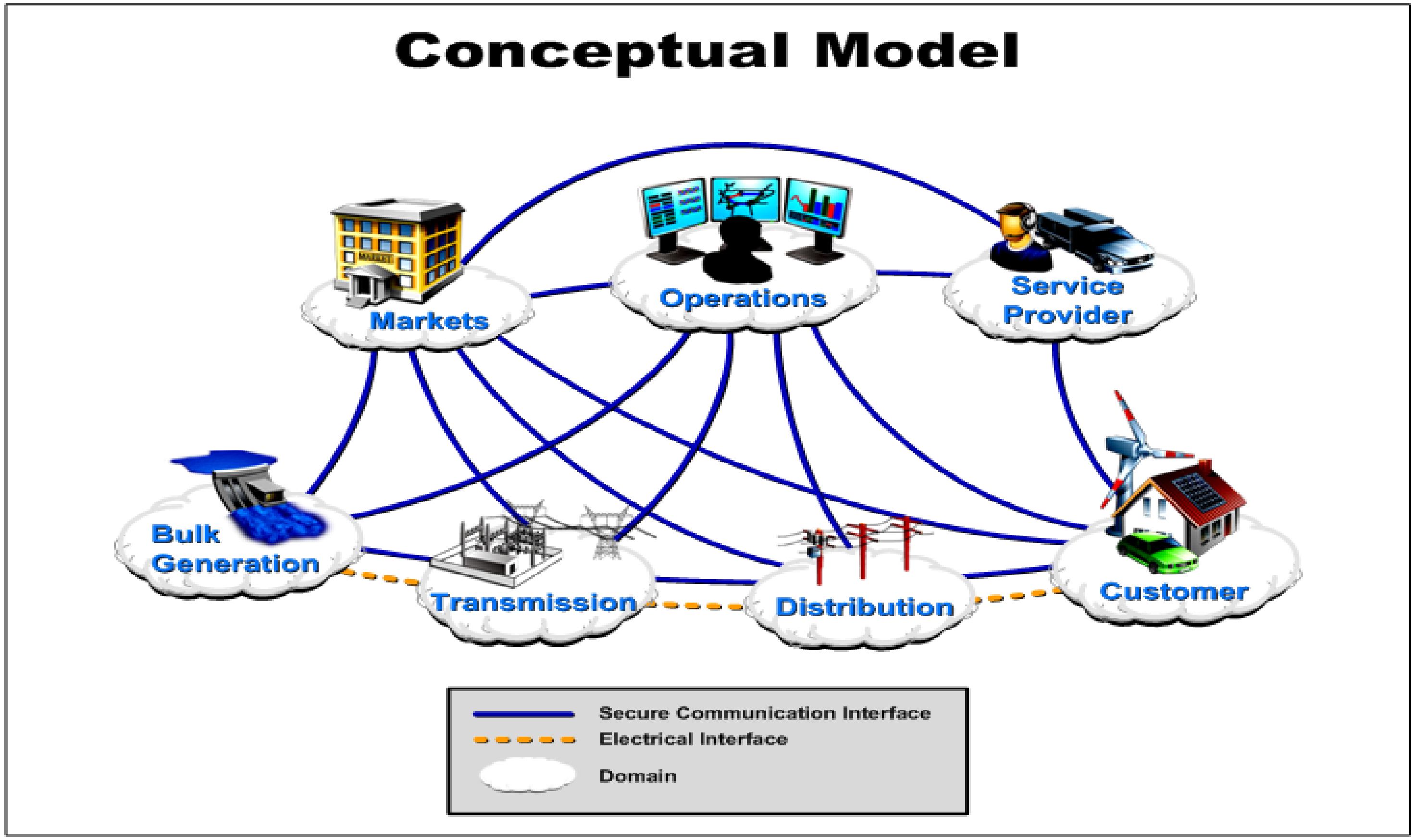


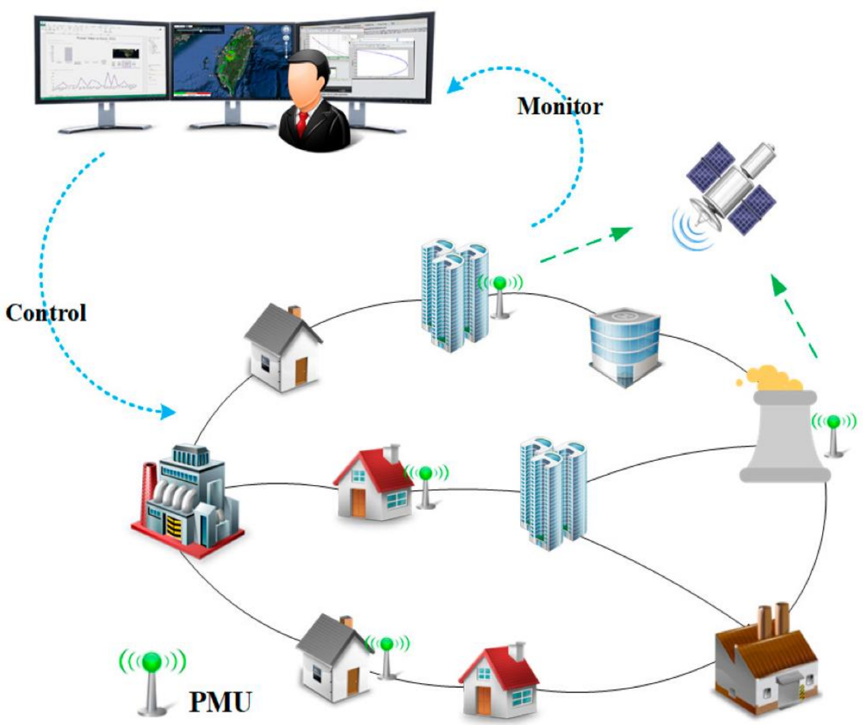
Fig. Smart Grid Conceptual Model by NIST

// National Institute of Standards and Technology (**NIST**) //

Wide Area Monitoring Systems (WAMS)

- Utilities have designed and employed WAMS, **to optimize transmission grid capacity and to avoid the spread of disturbances**.
- **By providing real - time information on stability and operating safety margins**, WAMS give early warnings of system disturbances for the prevention and mitigation of system - wide blackouts.
- **WAMS utilize sensors**, distributed throughout the network in combination with GPS satellites, **for precise time stamping of measurements in the transmission system**.
- The **integrated sensors will interface** with the communication network.
- Phasor measurement units (PMU) are a current technology that is a component of most smart grid designs.

WAMS Architecture



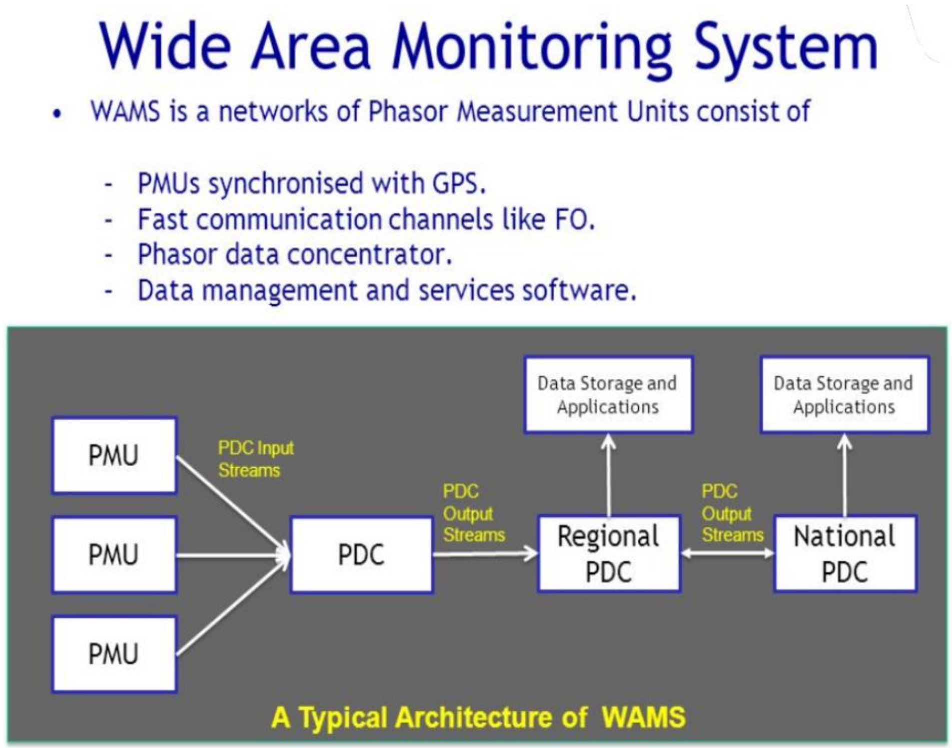


Fig. A general architecture of WAM

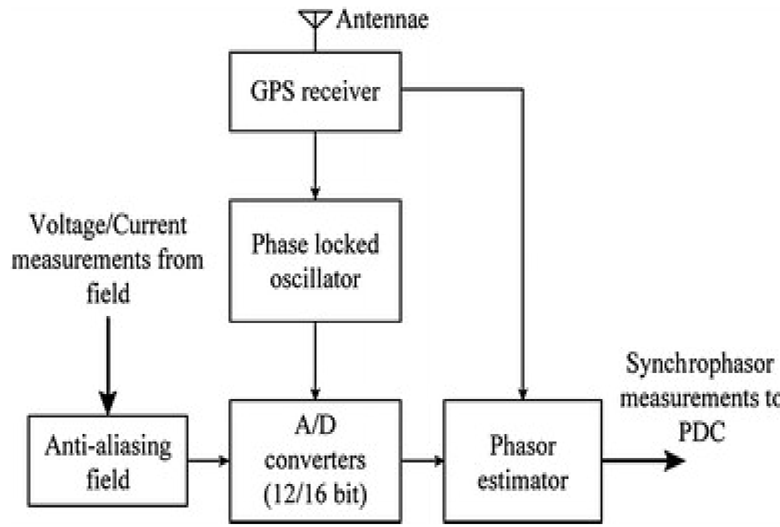
Phasor Measurement Units (PMU)/ ***(MPSM)***

- PMU (Synchrophasors) **give operators a time-stamped snapshot** of the PS.
- PMUs consist of **bus voltage phasors, branch current phasors, and information** such as locations, other network parameters.
- Precise phasor measurements **allows an operator to visualize exact** angular difference between different locations, situational awareness & ease congestion.
- PMUs are **equipped with GPS receivers, allow synchronization of readings, taken at distant points**.
- Instrumentation (u-processor) i.e. protection relays and disturbance fault recorders (DFRs); are incorporated within PMU module.
- PMUs ensure voltage & current with high accuracy at a rate of 2.88 kHz.
- PMU can calculate real power, reactive power, frequency, and phase angle 12 times per 60 hertz cycle. The actual sampling rate used to achieve this output is 1.4 MHz.
- IEEE standard on PMU/Synchrophasors: IEEE **C37.118**TM-2005 or **C37.118**

PMU Diagrams ***(MPSM)***

Fluke 6135A PMU

Macrodyne
1690 PMU



Block Diagram of PMU

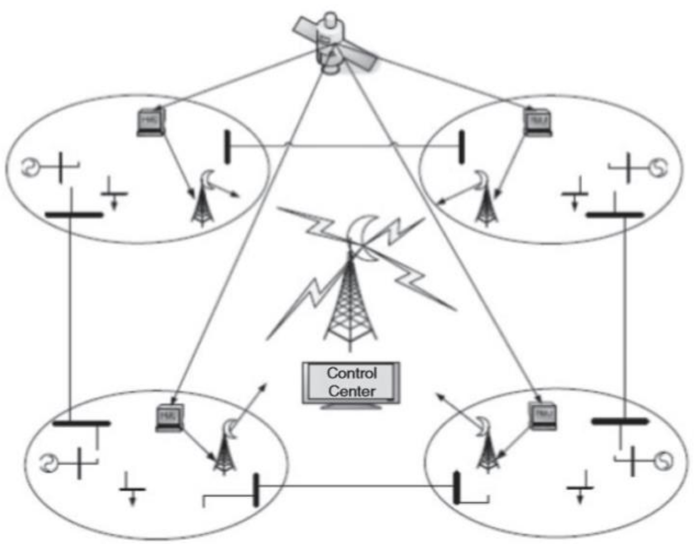


Fig: Conceptual diagram of a synchronized phasor measuring system with PMUs

Smart Meters ***(MPSM)***

- Smart meters have **two functions**:
  1. **providing data** on energy usage **to end customers** to help control cost and consumption.
  2. **Sending data to utility** for load factor control, peak-load requirements, and development of pricing strategies based on consumption information.

- Smart meters equip/enable customers with knowledge about **bill they pay per KWh** and **how and when they use energy**.

- Smart meters result in **better pricing information** and **more accurate bills** in addition to ensuring **faster outage detection** and **restoration by the utility**.

Smart Meters, ***(MPSM)***, Contd.

- Additional features will allow for demand - response rates, tax credits, tariff options, and participation in voluntary rewards programs for reduced consumption.

- Still other features will include remote connect/disconnect of users, appliance control and monitoring, smart thermostat, enhanced grid monitoring, switching, and prepaid metering.

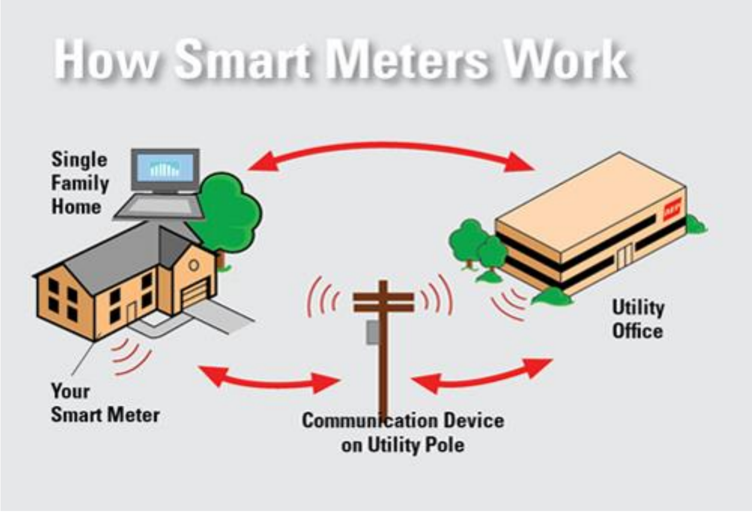
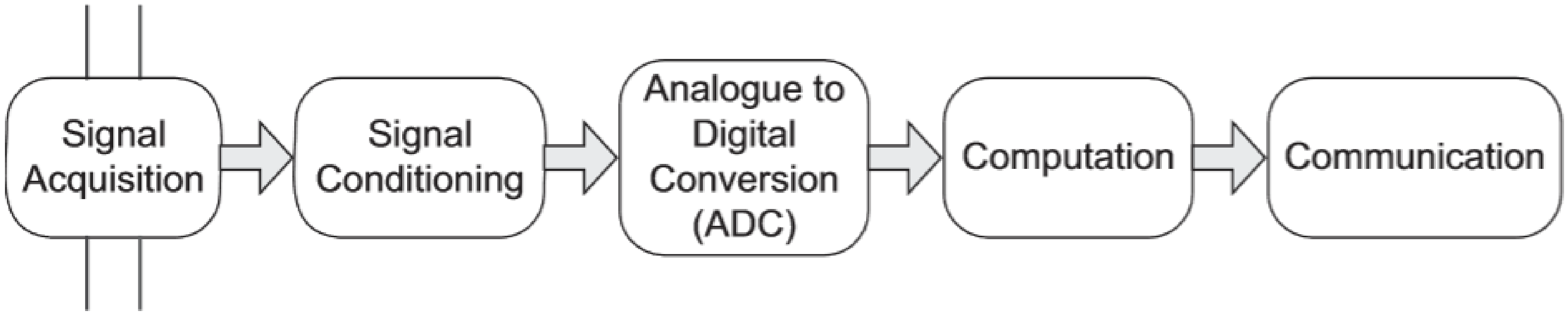


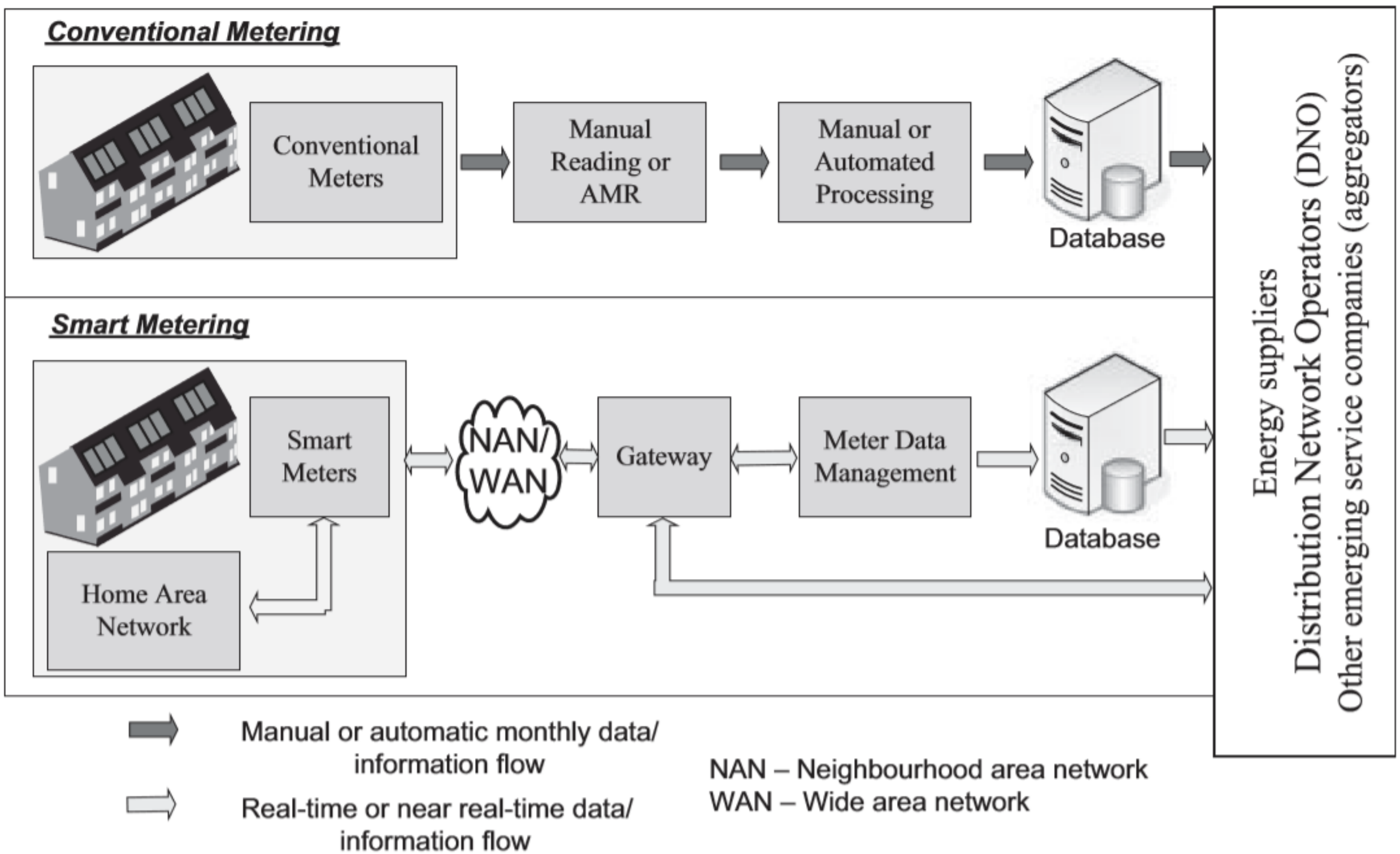
Fig Smart Meter Picture and simple working

Functional block diagram of a smart meter



1. **Acquire system parameters accurately and continuously for subsequent computation and communication**. Current and voltage sensors measure the current into the premises (load) and the voltage at the point of supply.
2. The **signal conditioning stage involves the preparation of the input signals for the next step in the process**, ADC.
3. Current and voltage signals obtained from the sensors are **first sampled and then digitized to be processed by the metering software**.
4. Computation requirements are **split into arithmetic operations** on input signals, time-stamping of data, preparation of data for communication
5. Smart meters **employ a wide range of network adapters for communication purposes**. The wired options include the Public Switched Telephone Network (PSTN), power line carrier, cable modems and Ethernet. The wireless options include ZigBee, infrared, and GSM/GPRS/CDMA Cellular.

Comparison of Conventional and Smart metering



Benefits/Advantages of AMI

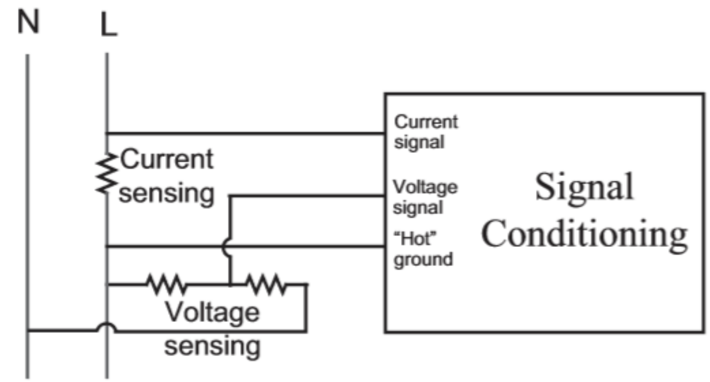
	Energy suppliers and network operator benefits	All benefit	Customer benefits
Short-term	Lower metering costs and more frequent and accurate readings	Better customer service Variable pricing schemes	Energy savings as a result of improved information
	Limiting commercial losses due to easier detection of fraud and theft	Facilitating integration of DG and flexible loads	More frequent and accurate billing
Longer-term	Reducing peak demand via DSI programs and so reducing cost of purchasing wholesale electricity at peak time	More reliable energy supply and reduced customer complaints	Simplification of payments for DG output
	Better planning of generation, network and maintenance	Using ICT infrastructure to remotely control DG, reward consumers and lower costs for utility	Additional payments for wider system benefits
	Supporting real-time system operation down to distribution levels Capability to sell other services (e.g. broadband and video communications)	Facilitating adoption of electric vehicles and heat pumps, while minimising increase in peak demand	Facilitating adoption of home area automation for more comfortable life while minimising energy cost

DSI: Demand Side Integration; DG: Distributed Generation; ICT: Information and communication technologies

Numerical (Assignment-1) 10 Min.

- The technical specification sheet of a smart meter states that its rated current is 120 A and power dissipation is 5W. It employs a current-sensing resistor of 220 μOhm.
  - When the load current is at the rated value of the meter, calculate:
    A. Power dissipation in all the current sensing resistor of the meter only
    B. Power dissipation in all the remaining components of the meter
    C. Voltage across the current-sensing resistor

Fig: Current and voltage sensing in Smart Meters



Smart Appliances ***(MPSM)***

- Smart appliances **cycle up and down in response to signals sent by the utility**.
- The appliances enable customers to participate in voluntary DR programs which **award credits for limiting power use in peak demand/grid under stress periods**.
- An **override function allows customers to control their appliances using the Internet**.
- Air conditioners, space heaters, water heaters, refrigerators, washers, & dryers represent about 20% of total demand/D/Y.
- Grid-friendly appliances **use a simple computer chip that can sense disturbances in the grid's power frequency and can turn an appliance off for a few minutes to allow the grid to stabilize during a crisis**.

Smart Appliances at a glance

Fig: Smart Appliances

Advanced Metering Infrastructure (AMI)

- AMI is the convergence of the electrical power grid, communication infrastructure, and supporting information infrastructure.

- The AMI functions can be subdivided into three major categories.

❖ <u>**Market Applications**</u>**:** Serve to **reduce/eliminate labor, transportation, infrastructure costs associated with meter reading**.

  - ➢ maintenance to increase accuracy of billing, and allow for time - based rates
  - ➢ While reducing bad debts; facilitates informed customer participation for energy management

❖ <u>**Customer Applications**</u>**:** Serve to **increase customer awareness about load reduction, reduces bad debt, and improves cash flow**,

  - ➢ enhances customer convenience and satisfaction; provides demand response and load management to improve system reliability and performance

❖ <u>**Distribution operations**</u>**:** curtails **customer load for grid management, optimizes network based on data collected, allows for the location of outages and restoration of service, improves customer satisfaction, reduces energy losses**.

  - ➢ Improves performance in event of outage with reduced outage duration and optimization of the distribution system and distributed generation management, provides emergency demand response

AMI and components at a glance

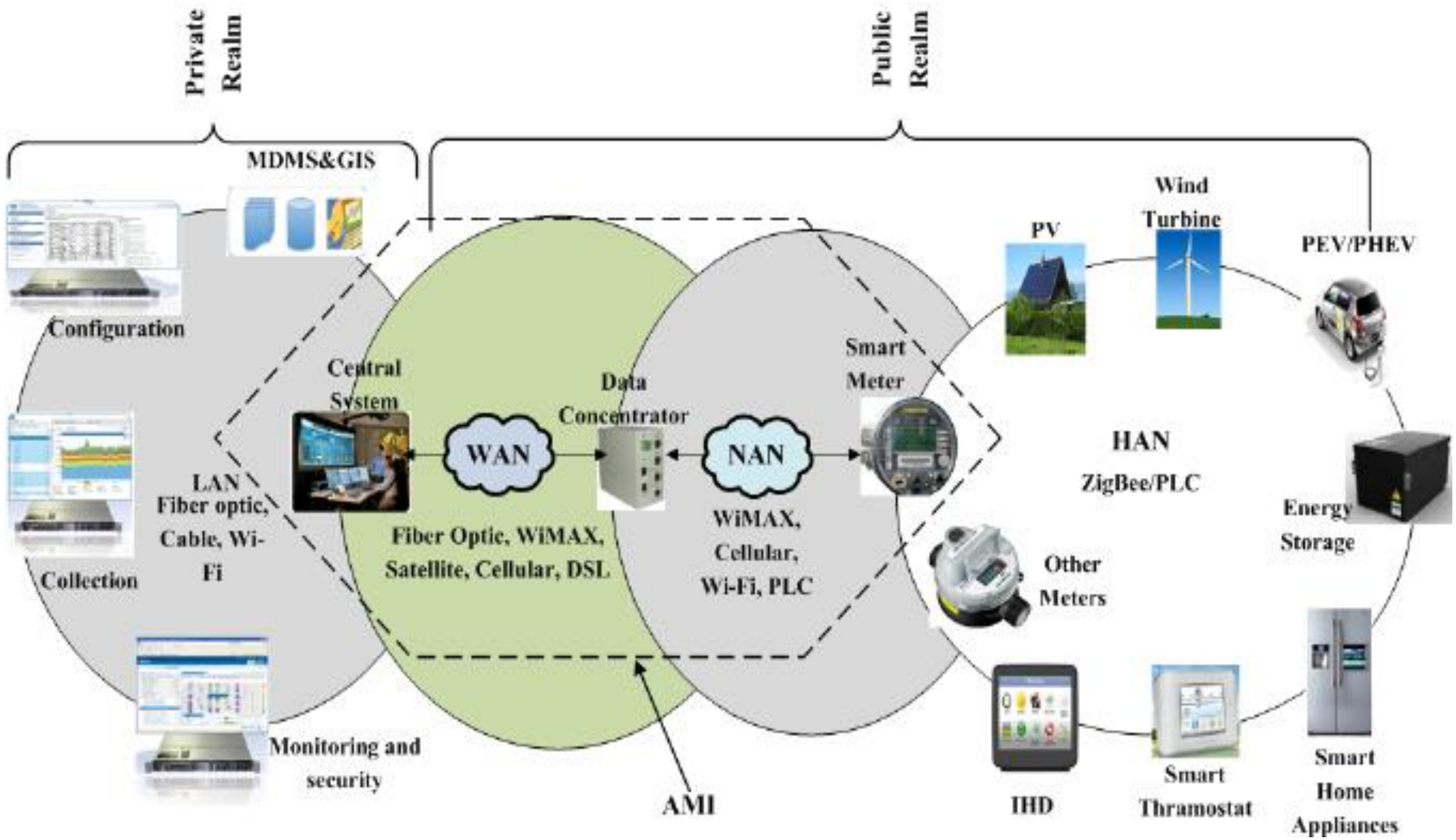


Fig: AMI Infrastructure and respective components

Demand-side integration

- **Demand-Side Integration (DSI)** is a set of measures to **use loads and local generation** to **support network operation/management** and **improve the quality of power supply**.

- DSI can help **defer investment in new infrastructure** by **reducing system peak demand**.

- In practice, the potential of DSI depends on:
  1. availability and timing of information provided to consumers,
  2. the duration and timing of their demand response,
  3. performance of the ICT infrastructure,
  4. metering, automation of end-use equipment and pricing /contracts.

DSI DEFINITIONS

- There are various terms in use with slightly different focuses.
- **Demand-Side Management (DSM):**
  - Utility activities that influence customer use of electricity.
  - This encompasses the planning, implementation and monitoring of activities designed to encourage consumers to change their electricity usage patterns.
- **Demand Response (DR):**
  - Mechanisms to manage the demand in response to supply conditions

DSI DEFINITIONS: Contd.

- **Demand-Side Participation:**
  - A set of strategies used in a competitive electricity market by end-use customers to contribute to economic, system security and environmental benefits

Services provided by DSI

- Demand-side resources such as **flexible loads, distributed generation and storage** can provide various services to the power system by **modifying the load consumption patterns**.

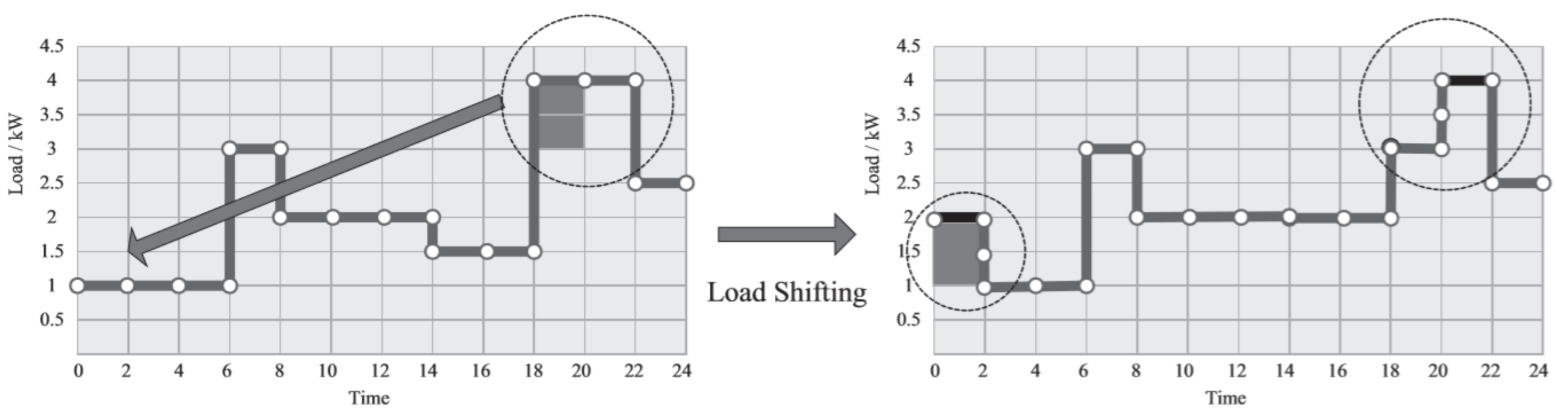
- Such services can include **load shifting, valley filling, peak clipping, dynamic energy management, energy efficiency improvement** and **strategic load growth**.

- Simple daily domestic load profiles are used to illustrate the function of each service.

Services provided by DSI: Contd.

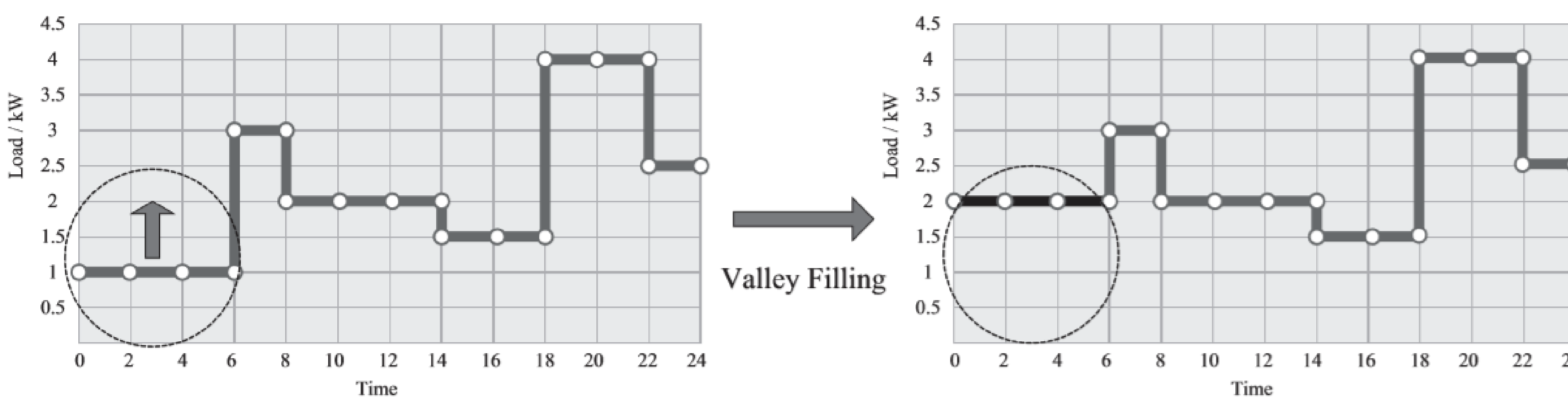
- **Load shifting** is the movement of load between times of day (from on-peak to off-peak) or seasons.

- In Figure below, a load such as a wet appliance (washing machine) that consumes 1 kW for 2 hours, is shifted to off-peak time.



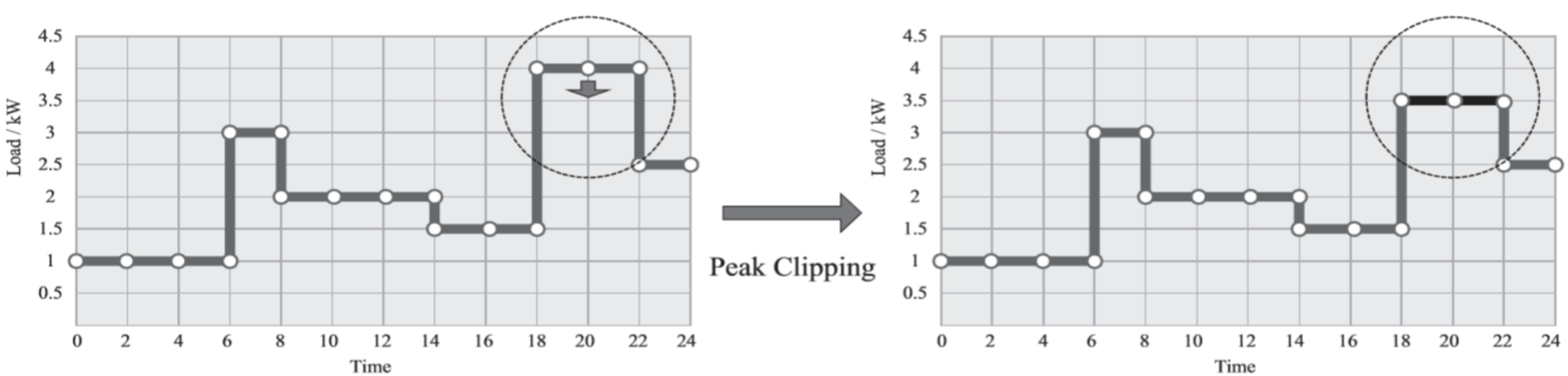
Services provided by DSI: Contd.

- **Valley Filling:** The main purpose of valley filling, which is to increase off-peak demand through storing energy, for example, in a battery of a plug-in electric vehicle or thermal storage in an electric storage heater.
- The main difference between valley filling and load shifting is that valley filling introduces new loads to off-peak time periods, but load shifting only shifts loads so the total energy consumption is unchanged.



Services provided by DSI: Contd.

- Peak clipping reduces the peak load demand, especially when demand approaches the thermal limits of feeders/transformers, or the supply limits of the whole system.
- Peak clipping is primarily done through direct load control of domestic appliances,
- For example, reducing thermostat setting of space heaters or control of electric water heaters or air-conditioning units. As peak clipping reduces the energy consumed by certain loads (in Figure, 2 kWh of energy is reduced), often consumers have to reduce their comfort.

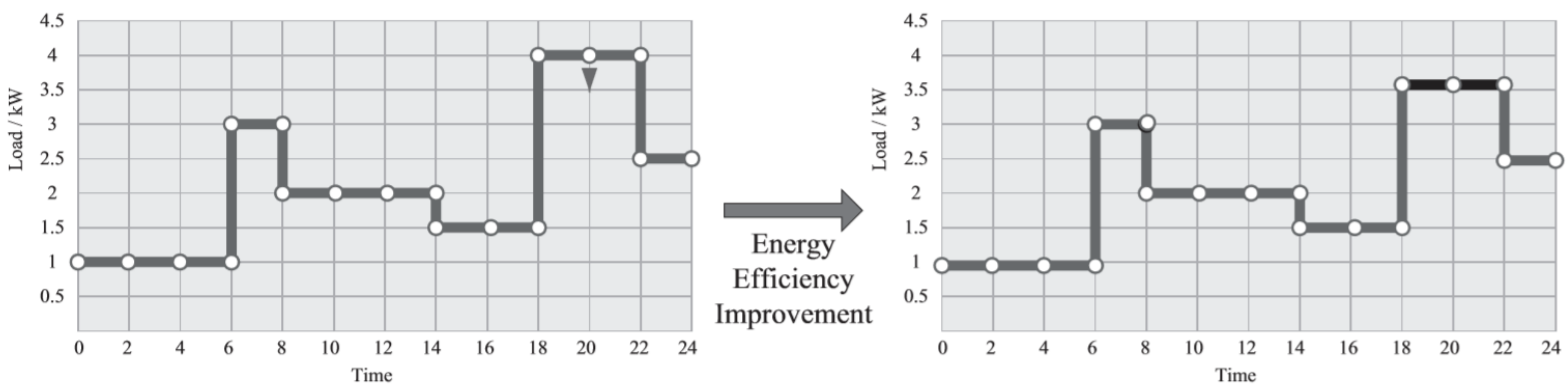


Services provided by DSI: Contd.

- **Energy efficiency programs** are intended to reduce the overall use of energy.
- Approaches include offering incentives to adopt energy-efficient appliances, lighting, and other end-uses; or strategies that encourage more efficient electricity use.
- For example, the feedback of consumption and cost data to consumers, can lead to a reduction in total energy consumption.

Services provided by DSI: Contd.

- Figure shows the reduction in energy demand when ten 60 W filament lamps (operating from 18.00 hrs to 22.00 hrs) are replaced by 20 W Compact fluorescent lamps.



Need for DSI

- With the deployment of smart metering and the development of home area automaton technologies, domestic appliances can be controlled in a more intelligent way, therefore bringing more flexibility to the demand side.
- The load shape is then flexible and can be controlled to meet the system needs.
- However, for the most effective DSI, the utility needs to know not only which loads are installed in the premises but which are in use.
- In this case two-way communication between the smart meter and network operators is necessary.

Implementations of DSI

- The implementations of DSI can be through price-based schemes or incentive-based schemes.
- **Price-based DSI** encourages customer load changes in response to changes in the electricity price.
- **Incentive-based DSI** gives customers load modification incentives that are separate from, or in addition to, their retail electricity rates.

Price-based DSI

- Tariffs and pricing can be effective mechanisms to influence customer behavior, especially in unbundled electricity markets.

- Price schemes employed include time of use rates, real-time pricing and critical peak pricing.

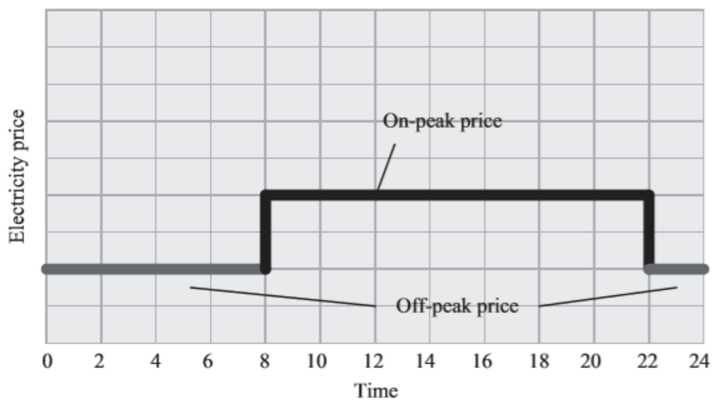
- **Time of use (ToU):**
  - ToU rates use different unit prices for different time blocks, usually pre-defined for a 24-hour day.
  - ToU rates reflect the cost of generating and delivering power during different time periods.

Price-based DSI: Contd.

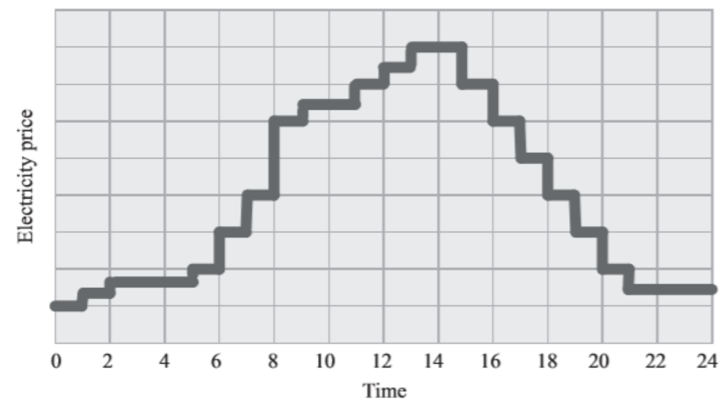
- **Real-time pricing (RTP):**
  - The electricity price provided by RTP rates typically fluctuates hourly, reflecting changes in the whole sale electricity price.
  - Customers are normally notified of RTP prices on a day-ahead or hour-ahead basis.

- **Critical peak pricing (CPP):**
  - CPP rates are a hybrid design of the ToU and RTP.
  - The basic rate structure is ToU.
  - However, the normal peak price is replaced by a much higher CPP event price under predefined trigger conditions
  - For example, when system is suffering from some operational problem or the supply price is very high).

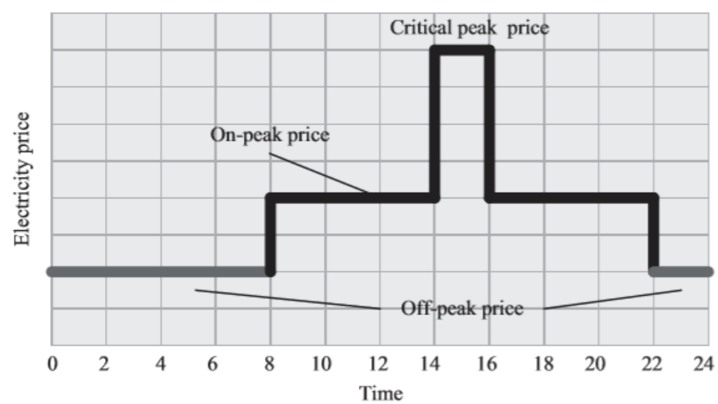
Price-based DSI: Contd.



Time of use pricing



Real-time Pricing



Critical peak pricing

Figure: Illustration of various pricing schemes

Price-based DSI: Contd.

- In price-based systems, the response of demand to price signals determines the DSI performance.
- Price elasticity is a measure used in economics to show the responsiveness, or elasticity, of the quantity demanded of a good or service to a change in its price.
- It gives the percentage change in quantity demanded in response to a 1 per cent change in price (holding constant all the other determinants of demand).

Price-based DSI: Contd.

- **Price elasticity of demand:** the percentage of change in demand as a result of a percentage of change in price (the elasticity should be a negative number).

$$\text{Price Elasticity} = \frac{\Delta D/D}{\Delta P/P}$$

- Where D is the demand, ΔD is the change in customer demand, P is the price, and ΔP is the change in the electricity energy price.

Price-based DSI: Contd.

- **Elasticity of substitution:** It is a measure of the percentage change in the **ratio of the peak to off-peak demand** as a result of a **percentage change in the ratio of the peak to off-peak price**.
- **Long-term price elasticity:** It is the annual energy consumption response to an average change in energy price.

Implementations of incentive-based DSI

Implementations	Description
Direct load control	Customers' electrical appliances (e.g. air conditioner, water heater, space heating) are controlled remotely (for example, shut down or tuned by the controller) by the program operator on short notice Direct load control programmes are primarily offered to residential or small commercial customers
Interruptible/curtailable service	Curtailment options integrated into retail tariffs providing a rate discount or bill credit for agreeing to reduce load during system contingencies Penalties may be introduced for failing to curtail Interruptible programs have traditionally been offered only to the large industrial (or commercial) customers
Demand-side bidding/ Buy-back programs	Customers offer bids for curtailment based on wholesale electricity market prices Mainly offered to large customers (for example, one megawatt and over) For small customers, third parties (for example, aggregators) are needed to aggregate loads and bid in the market on behalf of them
Emergency demand response programs	Provide incentive payments to customers for load reduction during periods when the system is short of reserve
Capacity market programs	Customers offer load curtailment as system capacity to replace conventional generation Customers typically receive intra-day notice of curtailment events Incentives usually consist of upfront reservation payments, and penalties for customer failure to curtail
Ancillary services market programs	Customers bid load curtailments in ISO /RTO (Independent System Operator/Regional Transmission Organisation) markets as operational reserves If their bids are accepted, they are paid the market price for committing to be on standby If their load curtailments are needed, they are called by the ISO/RTO, and will be paid the spot market energy price

Hardware Support for DSI Implementation

- The essential ICT infrastructure required for DSI can be provided by smart metering.
- In addition, load control switches, controllable thermostats, lighting controls and adjustable speed drives are required.
- Such equipment receives signals such as alarms or price signals and controls loads accordingly.
- 1. Load control switch:
    I. Electronic apparatus which consists of a communication module and a relay.
    II. It is wired into the control circuit of an air conditioning system, a water heater or a piece of thermal comfort equipment
    III. The communication module is used to receive control signals from the DSI program operator (or a HAN).
    IV. The time that the appliance will remain disconnected is generally pre-programmed (through an inbuilt clock).

Hardware Support for DSI Implementation. Contd.

- 2. Controllable thermostats:
  - It replaces conventional thermostats such as those on air conditioning systems or water heaters.
  - The DSI program operator (or a HAN) can increase or decrease the temperature set point through the communication module, changing the functioning of the equipment and hence the electricity load.

- 3. Lightning Load:
  - Lighting control equipment is used to manage the energy used by lighting in a more efficient way.
  - The achieved savings are based upon estimated average consumption, the time of use and user behaviour.

Hardware Support for DSI Implementation. Contd.

- 4. Adjustable speed drives (ASD):
  - ASDs allow electric motors driving pumps, ventilation units and compressors to function over a continuous speed range.
  - The loads of the majority of motorized appliances change over time and equipment is often operated at less than full load.
  - ASDs allow the motors to satisfy the required functioning conditions and to economize power and energy use when the system is not functioning at its maximum load.
  - Directly connected motors for pump and fans are often oversized and the fluid flow throttled for control.
  - Replacement of this system by an ASD can yield considerable saving of energy.

GIS AND GOOGLE MAPPING TOOLS

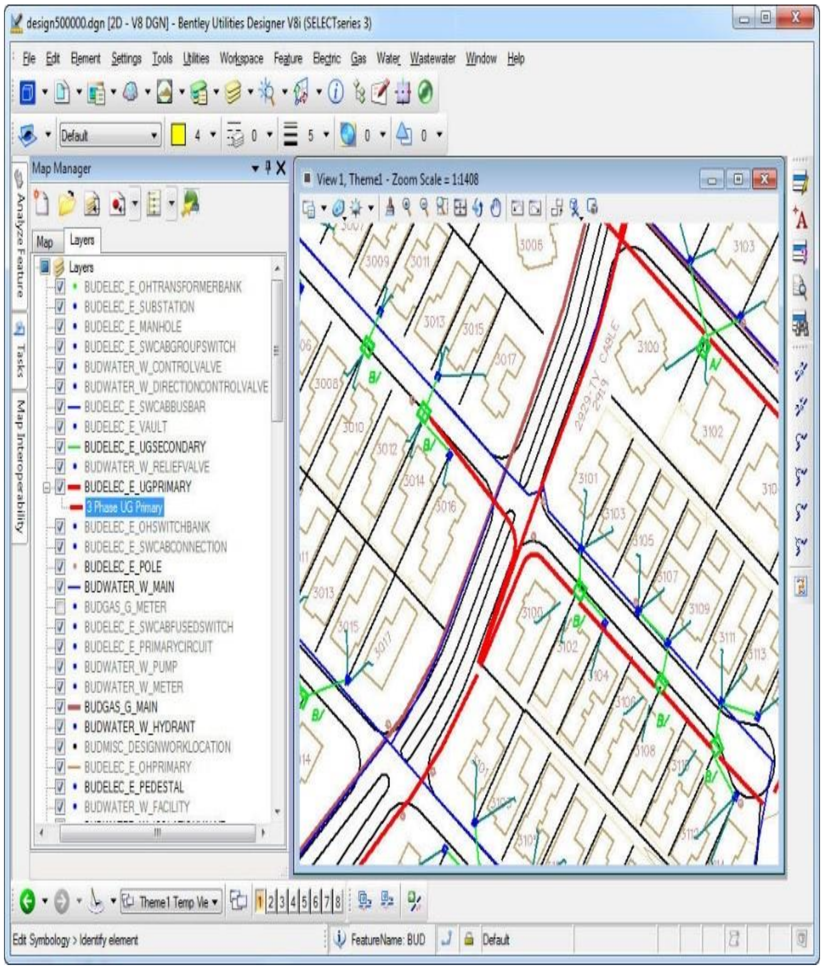
- GIS is useful for **managing traditional electric transmission and distribution and telecom networks**.

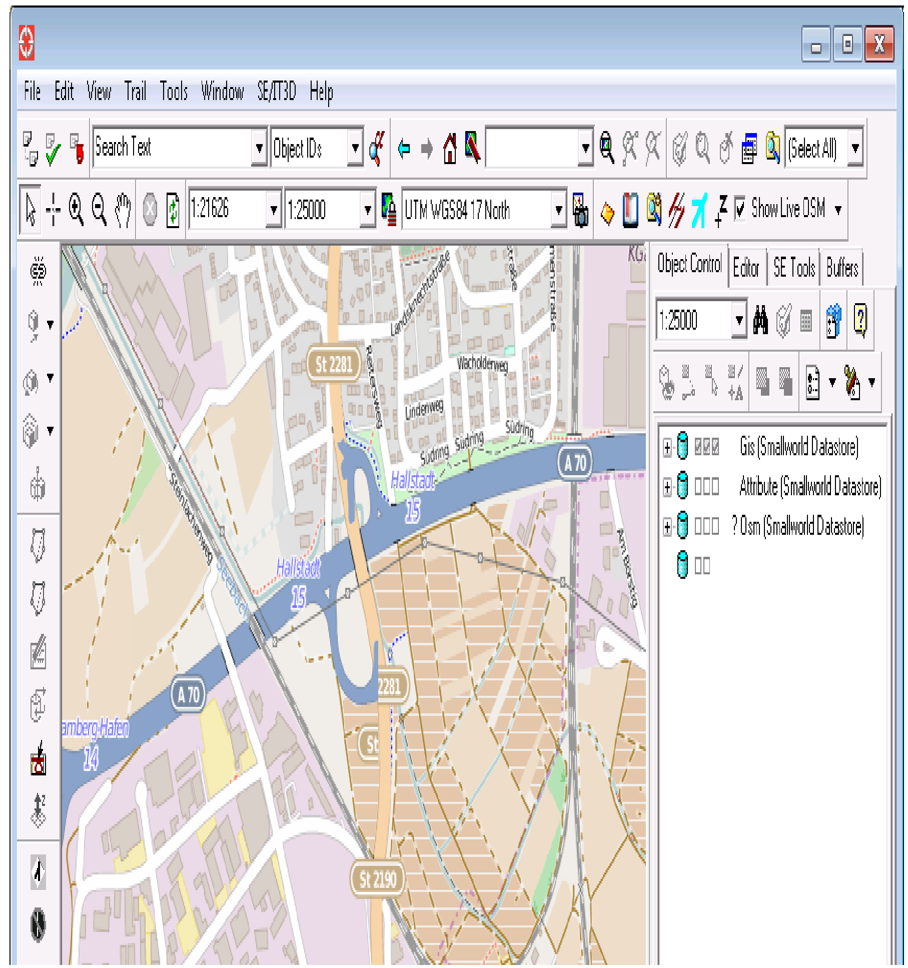
- It can also help to **manage information about utility assets for data collection and maintenance**.

- The **integration of GIS with Google Earth or other mapping tools will aid in understanding relationship of grid network to its surroundings**,
  - E.g., determining the optimal location of rights of way, placement of sensors and poles, and so on

- GIS technology will **provide partial context to operators & planners**:
  - E.g., real-time sensors collect the data needed to reconfigure networks, for reducing outages and equipment failures.

Research and commercial GIS based Tools





Needs for future grid

- Trends in the development of the electric power system and the expectation of future demand suggest the following needs:

1. Reducing outage time
2. Preventing power theft which causes large unaccounted losses
3. Effective system for collection and billing system
4. Expanding services for customers
5. Effective asset management
6. Improving reliability for distribution networks such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index)
7. Improving analysis of customer complaint logs
8. Enhancing load flow power quality analysis and fault study for current and anticipated problems
9. Scheduling of actions such as load shedding and vegetation control

MULTIAGENT SYSTEMS (MAS) TECHNOLOGY

- MAS are a computational system in which several agents cooperate to achieve a desired task.
  - The performance of MAS can be decided by the interactions among various agents, which cooperate to achieve more, as shown below.
  - The MAS architecture enhances monitoring and measurement schemes within the SG environment and is utilized as a detection and diagnosis device and in power system monitoring.
  - Information passes between the agents about the appropriate actions to be taken. When implemented, the process repeats itself to constantly monitor the system for managing conditions immediately.

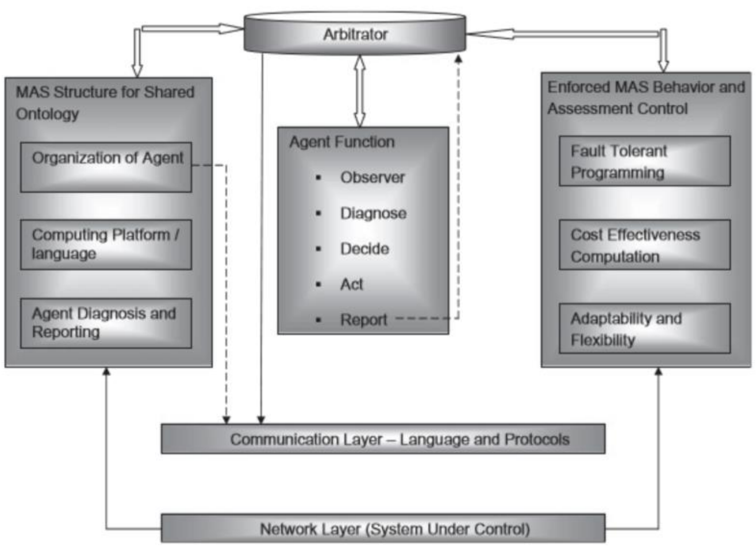


Fig. Simplified multi-agent system (MAS) architecture.

1. Arbitrator Agents (AA)
2. System Monitoring Agents (SMA)
3. Fault Detection Agents (FDA)
4. Diagnosis Agents (DA)
5. Judgment Index Agent (JIA)
6. Scheduling Agent (SA)

MAS for Smart Grid Implementation

- SG integrates advanced sensing technologies, control methods, and integrated communications into the present electricity grid at both T&D levels.
- In conventional electric power systems, exchanging system status and control signal is accomplished by SCADA.
- A MAS as a current trend, is a combination of several agents working in collaboration pursuing assigned tasks to achieve the overall goal of the system.
- Besides it has become an increasingly powerful tool in developing complex systems that take advantages of agent properties: autonomy, sociality, reactivity and pro-activity, etc.
- The MAS is autonomous in that they operate without human interventions, proactive because of goal oriented behavior by taking initiatives and communicate with other agents as well.

Multiagent Specifications

- Specifications of agents in the Intelligent Distributed Autonomous Power System (IDAPS) MAS are defined as follows:

1. **Control agent:** Duties include monitoring system's V & f to detect contingency situations or grid failures, and
   - sending signals to the main CB to isolate the IDAPS micro-grid from the utility when an upstream outage is detected
   - receiving electricity price ($/kWh) signal from the main grid, obtained from AMI, and report them to the IDAPS entities

2. **Distributed energy resource (DER) agent:** Duties include storing associated DER information, monitoring and controlling DER power levels and connect/disconnect status;
   - DER information to be stored may include DER identification number, type, rating (kW), local fuel availability
   - cost function or price at which users agree to sell, DER availability, that is, planned maintenance schedule

Multiagent Specifications, Contd.

3. User agent: It acts as a customer gateway that makes features of an IDAPS microgrid accessible to users;

- Duties include providing users with real-time inform on entities residing in the IDAPS system;
- Monitors electricity consumption by each critical and noncritical load; allows users to control the status of loads based on user’ s predefined priority.

4. Database agent: It serves as a data access point for other agents as well as users;

- Responsibilities include storing system information, recording messages and data shared among agents.

Multiagent Technique

- An agent of a MAS may be defined as an entity with attributes considered useful in a particular domain.
- In this framework, an agent is an information processor that performs autonomous actions based on information.

- Common agent attributes include:

1) **Autonomy:** Goal-oriented, proactive & self-starting behavior
2) **Collaborative behavior:** The ability to work with other agents to achieve a common goal
3) **Knowledge - level communication ability:** The ability to communicate with other agents with language resembling human speech acts rather than typical symbol level program - to - program protocols
4) **Reactivity:** The ability to selectively sense and act
5) **Temporal continuity:** Persistence of identity and state over long periods

Multiagent Technique, Contd.

- MAS can be characterized by:

i. Each agent has incomplete capabilities to solve a problem
ii. No global system control
iii. Decentralized data
iv. Asynchronous computation

MAS Example:

An example of MAS architecture in action is a power failure on board a ship that is caused by an internal system error, an external contingency from battle, and so on.

Clearly, the goal is rapid restoration of the onboard power supply; hence, when a fault occurs, the protection system will isolate the fault, allowing the system to restore power to a target configuration after the outage

MICROGRID AND SG COMPARISON

1. Microgrid (MG): Main attributes of MG are as follows:

1. A MG is a local island grid that can operate as a stand-alone or as a grid - connected system
2. Powered by gas turbines or renewable energy and includes special purpose inverters and a link for plug - and - play to the legacy grid
3. Special purpose filters overcome harmonics problems while improving power quality and efficiency
4. Local power provider with limited advanced control tool

2. Smart Grid: In slide 3.

1. smart grid is a wide area provider with sophisticated automated decision support capabilities.