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 System (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)

Modern Power Grid

Roadmap towards reducing CO_2 emissions and restricting the growth of greenhouse gases:

- Renewable energy sources integrated to power grid
- Switching to Electric vehicle transportation, PEV and PHEV
- Integrating Battery Energy Storage Systems (BESS) or an Energy Storage Systems (ESS) into the current network

Renewable energies are characterized by their variable and intermittent production

- Using a combination of several RES, as well as the ESS and the back-up sources, the intermittent nature of RES can be avoided

However, this intermittency can significantly affect:

- voltage profile of the system
- interfere with conventional on-load tap changer control systems
- negative effect on the performance of the power grid

Modern Power Grid

New challenges faced by modern power grid:

- GHG mitigation
- uncoordinated grid parameters
- raised system complexities
- intermittent renewable generation
- high PEV price requirements
- power quality issues
- energy imbalance
- Flexibility
- loss of reliability
- system security
- regulatory issues such as unequal distribution of benefits to consumers
- shift from a traditionally passive to an active distribution system (prosumers)

The concept of Energy Management

Balancing energy production and utilization is known as energy management which can have major influences on the journey of electric energy from production to utilization

Energy management in power distribution systems considers various traditional energy sources in addition to smart grid components like energy storage systems, renewable energy sources, and critical loads

Energy management system in the smart grid performs a major role in functioning and management so that the power system strategy works more effective by examining, regulating, and conserving energy

Integration of smart grid with energy management system can evaluate complicated power system data, decrease power utilization, and enhance smart grid reliability and effectiveness

Definition of EMS

- The IEC 61970 standard of the International Electrotechnical Commission has defined an Energy Management System (EMS) as:

A computer system that comprises a software platform providing essential support services, and a set of applications providing the functionalities necessary for the efficient operation of power generation and transmission facilities to ensure security of energy supply at minimum cost

Definition of EMS

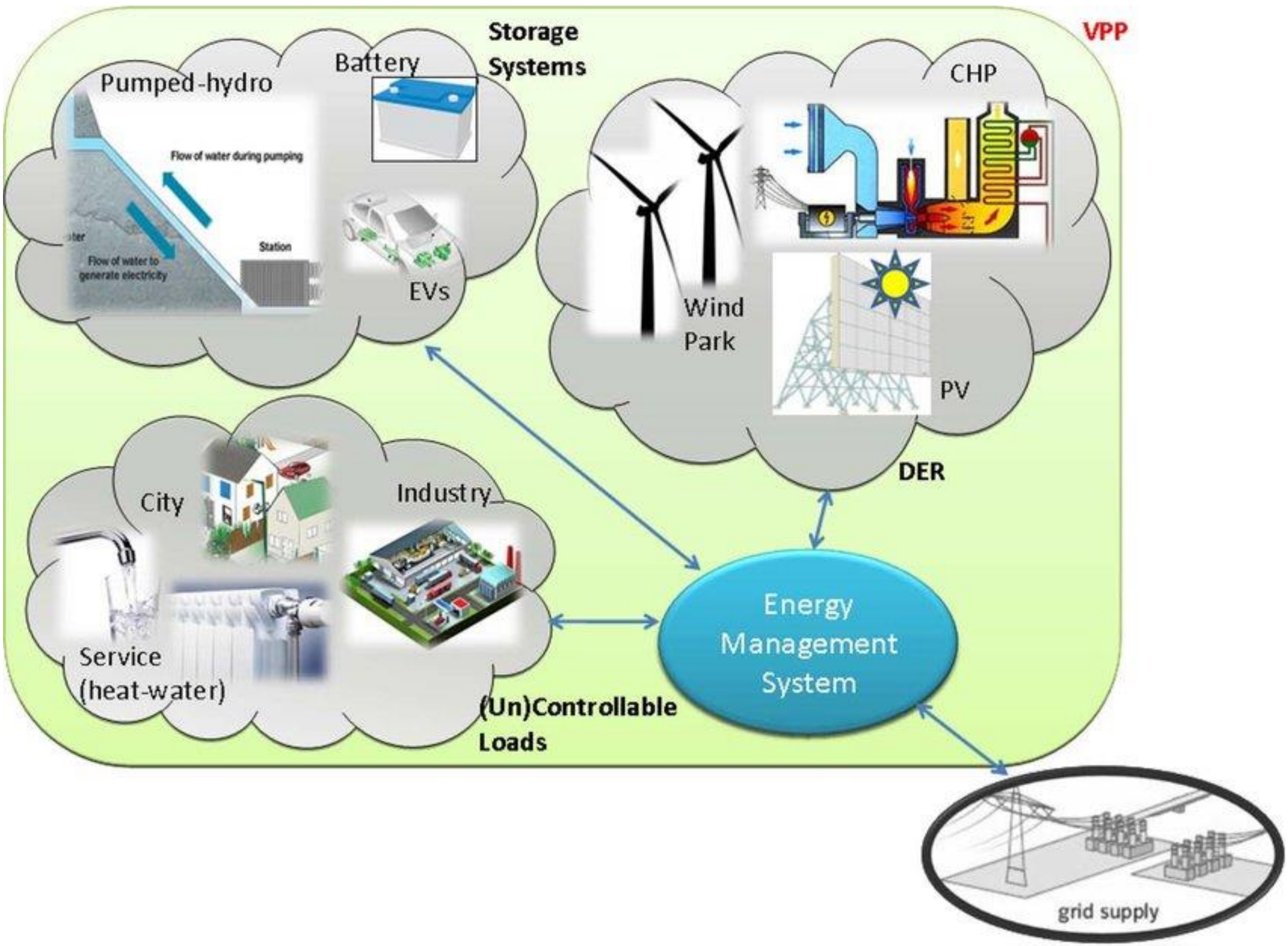
Therefore, the flow of energy between sources must be controlled when there is more than one energy source and storage systems

An Energy Management System (EMS) is very important:

- In order to ensure that the potential of new sources and new types of loads on the electricity network is exploited to the maximum and that their negative impacts are minimized
- to ensure load continuity in all conditions and to improve the stability of the electricity network
- It also includes optimization, which ensures a reduction in the cost of power generation

Thus, the EMS manages and reduces to a minimum the quantity and price of energy needed for a particular application by grouping all systematic procedures together

Definition of EMS



EMS Advantages and Challenges

Advantages

- Cost-effective solutions
- Easy configuration and maintenance
- Helps to identify efficient electrical equipment
- Graphical display of energy consumption
- Facility of viewing real time electrical data and energy reports
- Lower energy cost
- Lower environmental impacts
- Increased energy security

Challenges

- Energy baseline development
- Adjustment to energy baseline
- Operational savings
- Excessive finance charges
- Require AMC
- Quality control
- Labour intensive
- Requires technical insight
- Low scalability

Evolution of EMS

The evolution of the EMS began in the 1960s, which was termed as a control center, and later came to be known as energy control center (ECC) during 1970s

It was further renamed as supervisory control and data acquisition-EMS (SCADA-EMS) when SCADA system based on advanced computer came into existence during the early 1990s

It finally evolved into real time known as EMS, which includes various control techniques like load control (LC), demand-side management (DSM), and distribution management system (DMS)

Function of EMS

The function of EMS is to optimally allocate different energy sources to the customers along with integrating sustainable power sources without compromising the reliability, security, and safety of the system.

An EMS can monitor, supervise, optimize, and control the consumers, distribution, transmission, and generation facility

Thus, the prime duty of EMS is to create a balance between supply and demand in an efficient manner, which should be cost-effective within operating constraints and uncertainties (uncertainties in the EMS architecture include variation in generation from renewable energy resources, electricity price, and customers' behavior)

EMS State-of-the-art

It can work for real-time SCADA applications, dispatch, control, energy scheduling, and accounting as well as transmission security management

The EMS is becoming more and more complicated, as the grid is evolving with the integration of PEV and RES, ESS, buildings high power requirement, and many more factors.

However, the internet of things (IoT) and machine learning are gaining popularity simultaneously, and both are very helpful for the efficient functioning of the EMS in the network

Objectives of EMS

Technical Objectives

- improving power quality
- cost reduction by precisely monitoring and observing the loads and energy resources
- better outage management by balancing generation, storage, and load
- reducing distribution system losses
- improved life expectancy of power system equipment
- reduce maintenance and downtime
- integration of PEVs, ESS, and RES with proper coordination

Economic objectives

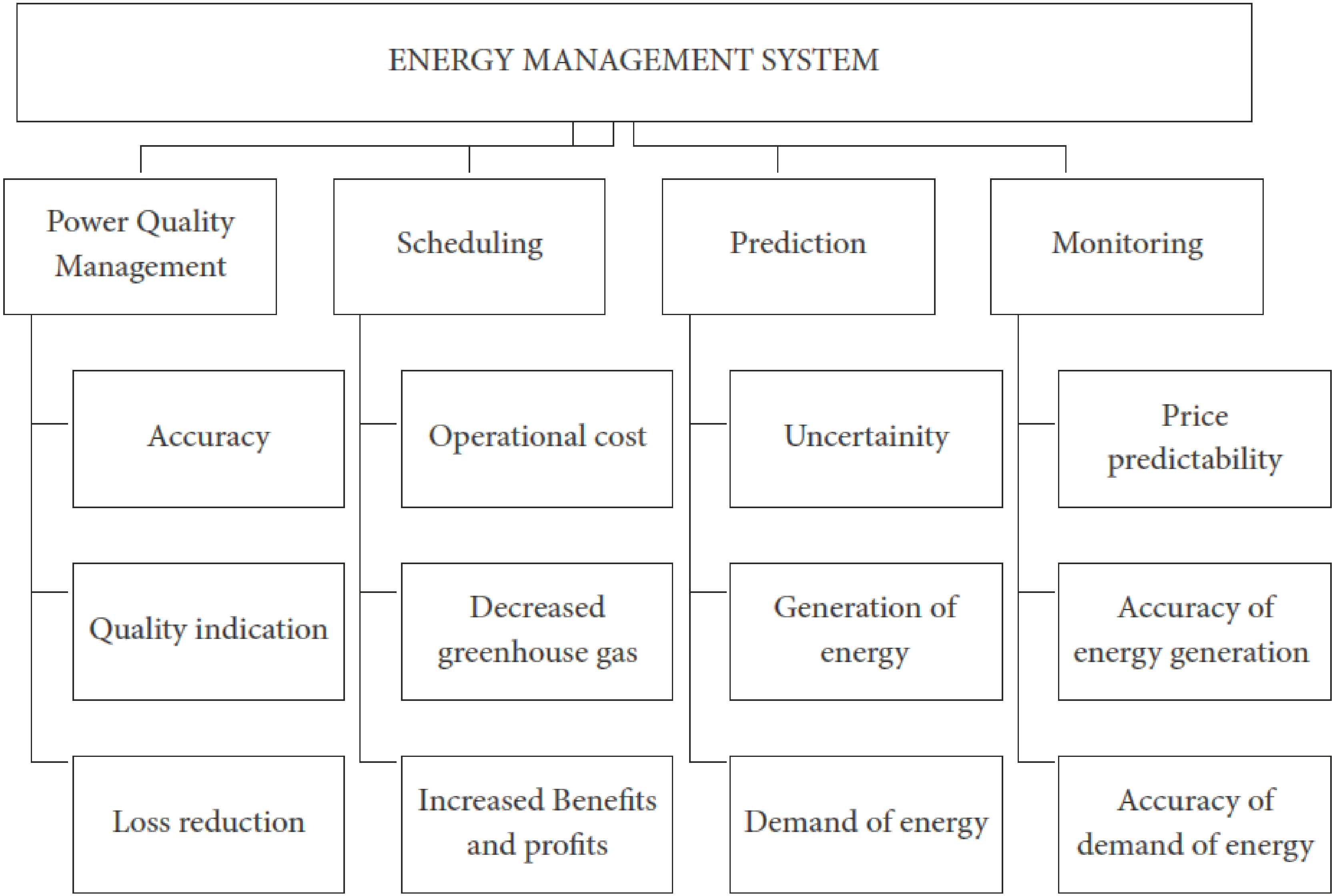
- reduce total operating cost of energy
- cost to the customers
- profit maximization of aggregators and parking lot owners etc.

Objectives of EMS

Environmental objectives

- GHGs emission minimization
- achieve low carbon footprint generation

Components of EMS



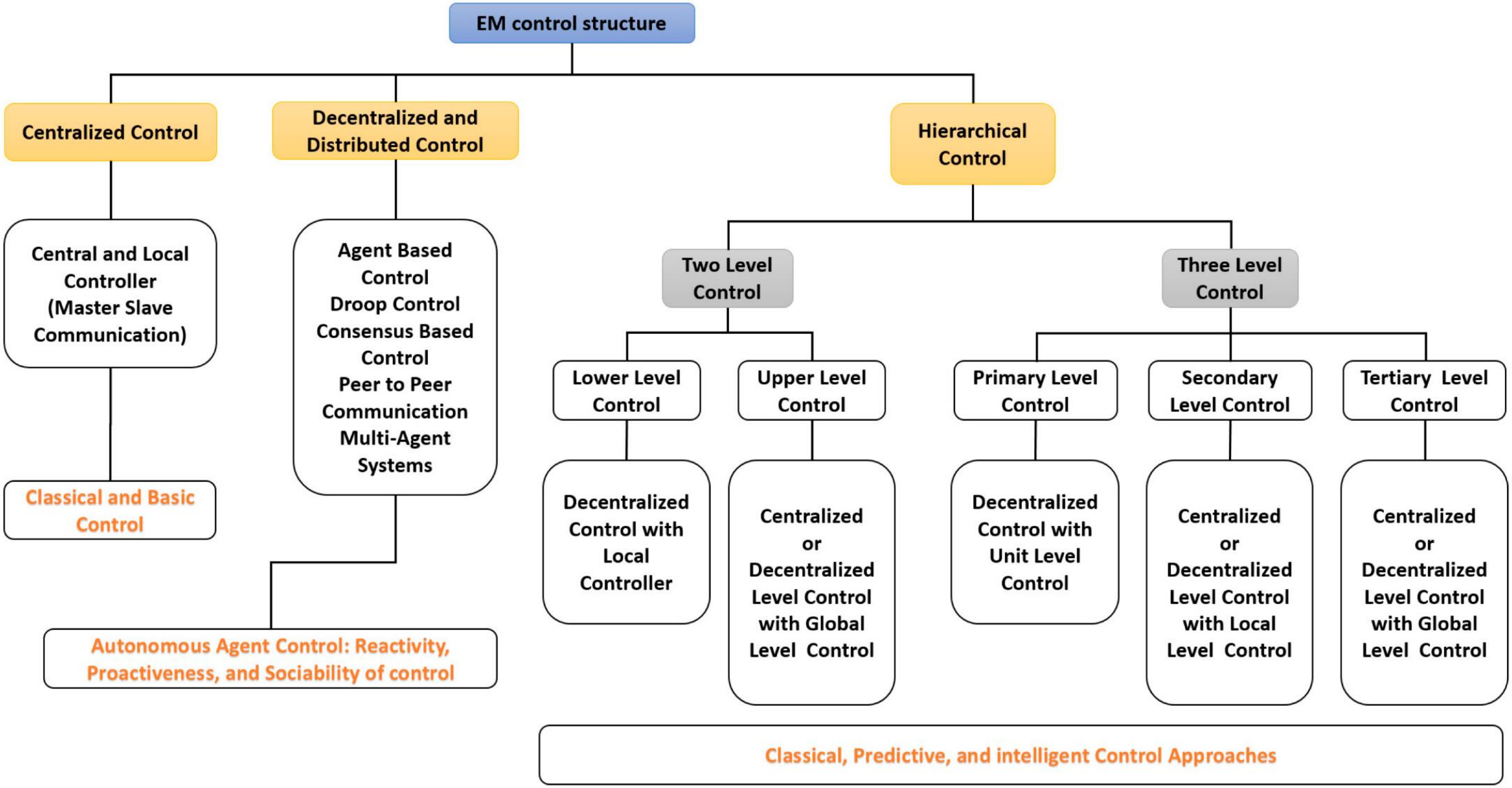
Architecture of EMS

Efficacy of EMS depends on the control architecture of the EMS, and the adopted solution approach

Commonly used EMS architectures are:

- centralized
- decentralized (distributed)
- hierarchical

Architecture of EMS



Centralized EMS

The centralized EMS architecture is characterized by:

- one central controller with a high-performance computing unit
- a dedicated, secure communication network to manage the utilization of energy

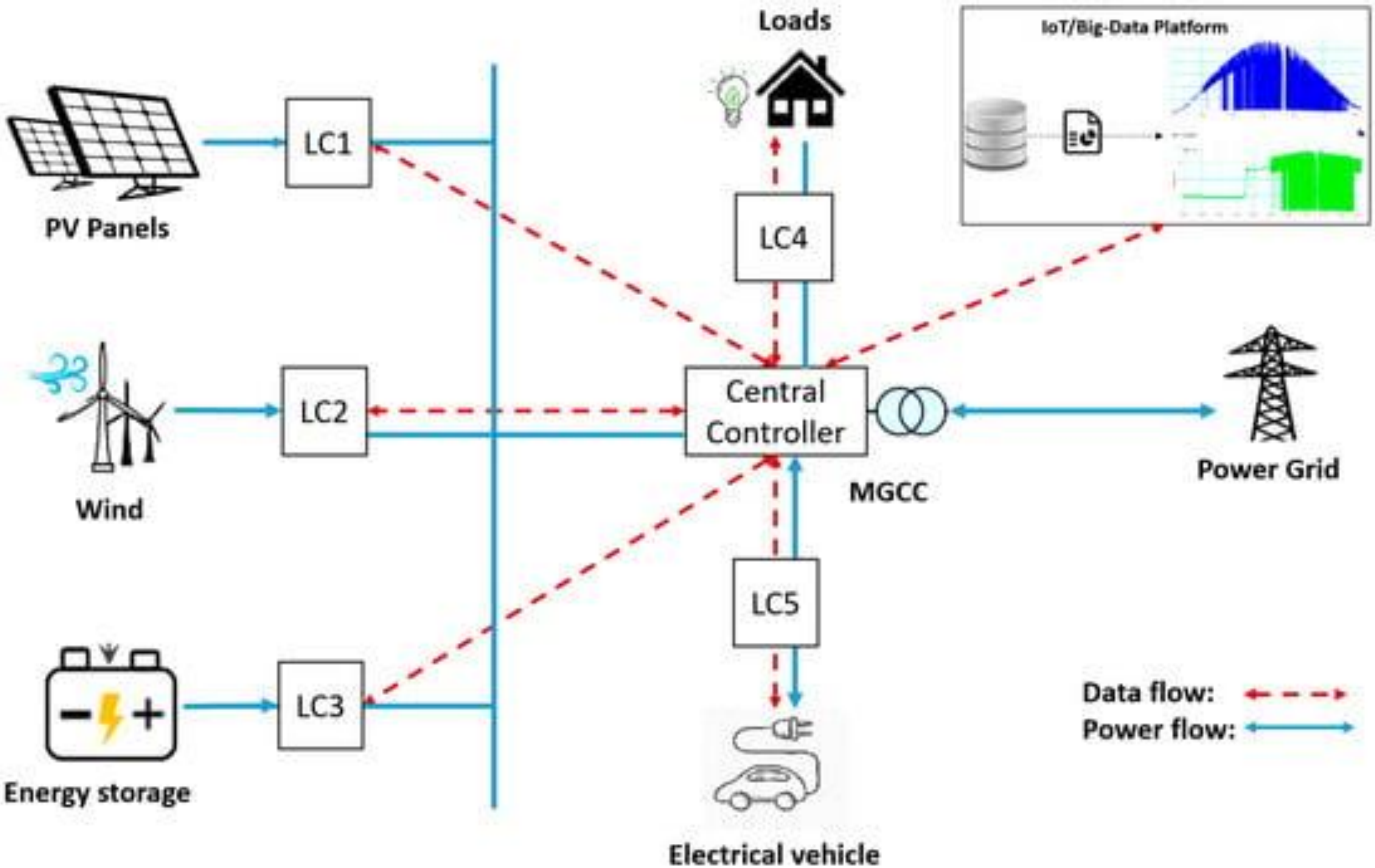
The central controller may be a utility or an aggregator, which collects the following information from all nodes to execute the optimization programs to meets its objectives for efficient operation:

- energy generation of DER
- energy consumption pattern of each load/consumer, meteorological data,
- other required information from market operators (MOs), etc.

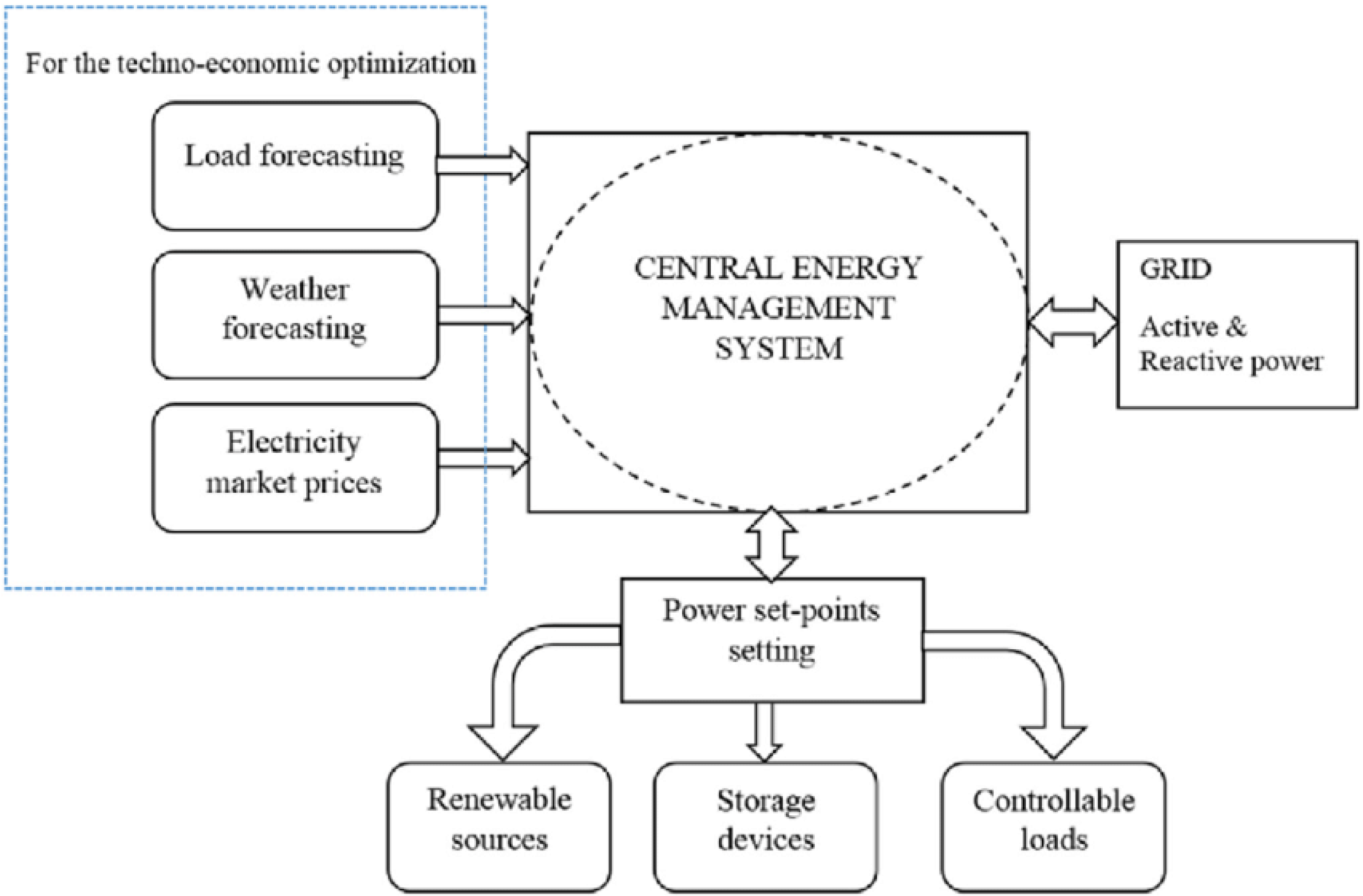
This centralized control structure provides optimal global performance

Centralized EMS

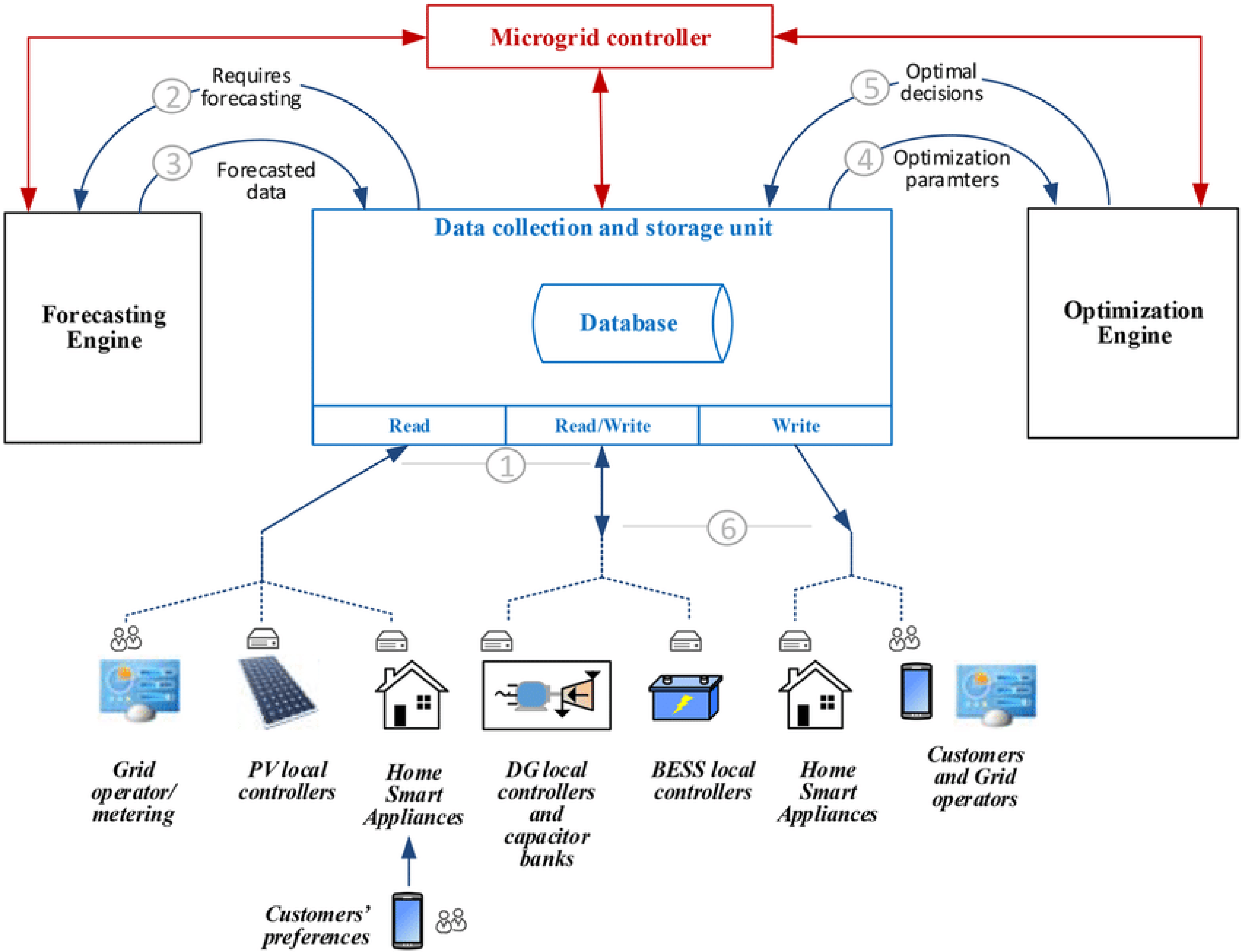
Centralized EMS



Centralized EMS



Centralized EMS



Centralized EMS

Limitations of centralized EMS architecture:

- Since all information is gathered and handled at one place, the computational burden increases, especially if a large number of assets are to be controlled, thereby making this control structure less effective for real-time communication requirements
- The centralized EMS architecture is difficult to expand and may get interrupted on integrating a new source/component, which has different operating cost and constraints
- Moreover, it entails a single point of failure

Centralized EMS

Objective

- Total operating cost minimization

Merit

- Global optimization
- Reduction in overall operating cost
- Uniform for the whole network, so easy to implement

Demerit

- Customer privacy is less
- A dedicated strong communication link is needed
- Computational burden is high
- Involves single-point failure
- Poor flexibility and expandability

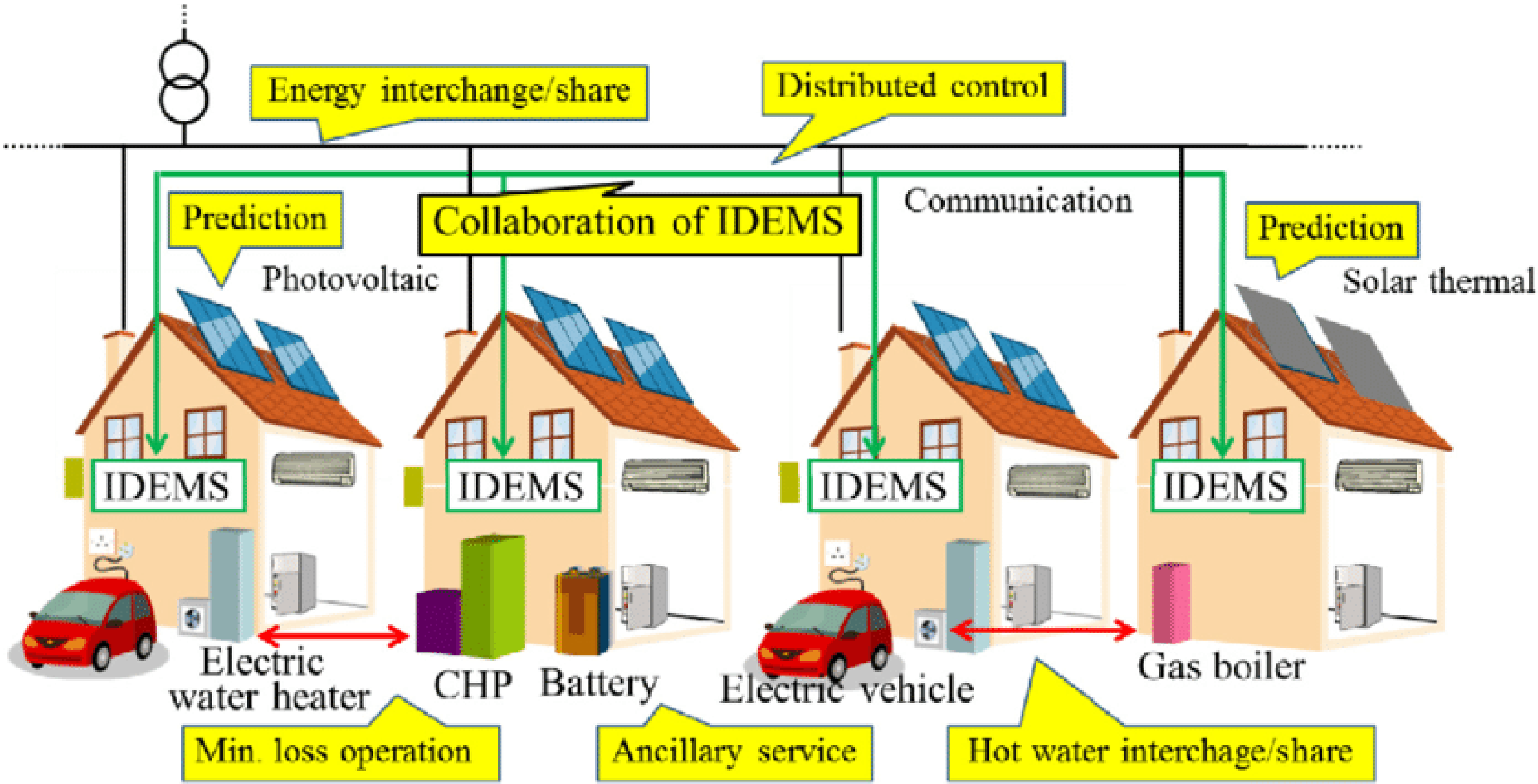
Decentralized/Distributed EMS

The decentralized EMS architecture is characterized by distributed processing system with each node having autonomous control capability and peer-to-peer communication with other nodes.

Thus, the decentralized EMS architecture overcomes the limitations of the centralized architecture by:

- enhancing the expandability
- allowing greater flexibility of operation
- avoiding single-point failure

Decentralized/Distributed EMS



IDEMS – Integrated Distributed Energy Management System

Decentralized/Distributed EMS

The distributed control can be considered as a decentralized control in which local controllers (LCs) use local measurements, such as frequency and voltage values, to elect the leader entity

They are also allowed to share information with neighbors

For a distributed control, LCs do not only use local measurements but also are able to send and receive required information to other LCs

In decentralized control approaches, limited local connections are required and the control decisions are made based only on local measurements

It does not require a high-performance computing unit and a high-level connectivity

Decentralized/Distributed EMS

Depending on the level of decentralization and communication network available, the decentralized architecture can be categorized into three modes of operation:

- fully dependent
- Fully independent
- partially independent

Decentralized/Distributed EMS

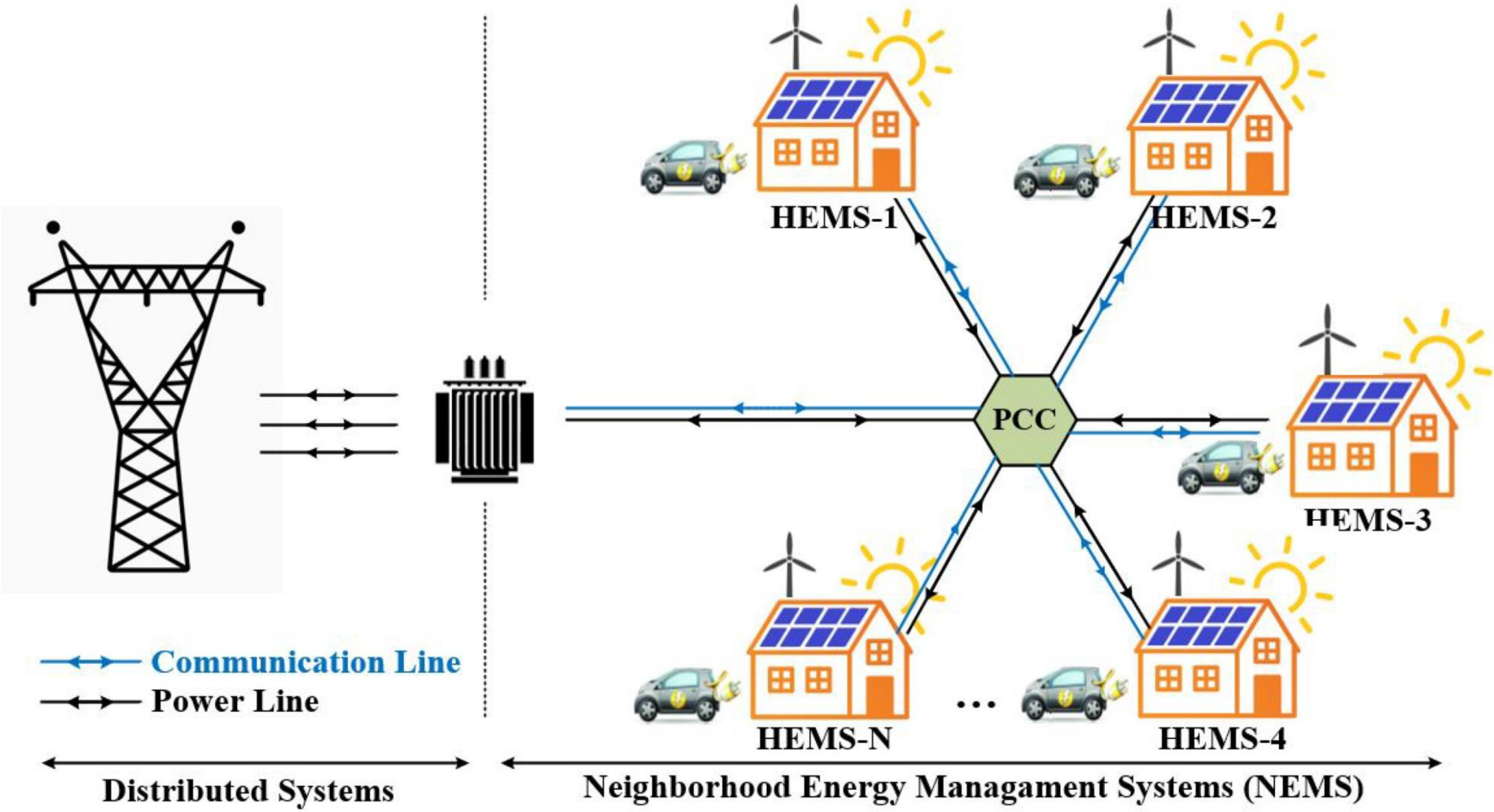
In the fully dependent mode of operation, the local/distributed controllers communicate with each other via a central entity

- Though the communication among local controllers is dependent on a central entity, the decision is taken by themselves and not the central entity

In fully independent structure, communication between local controllers is independent of a central entity

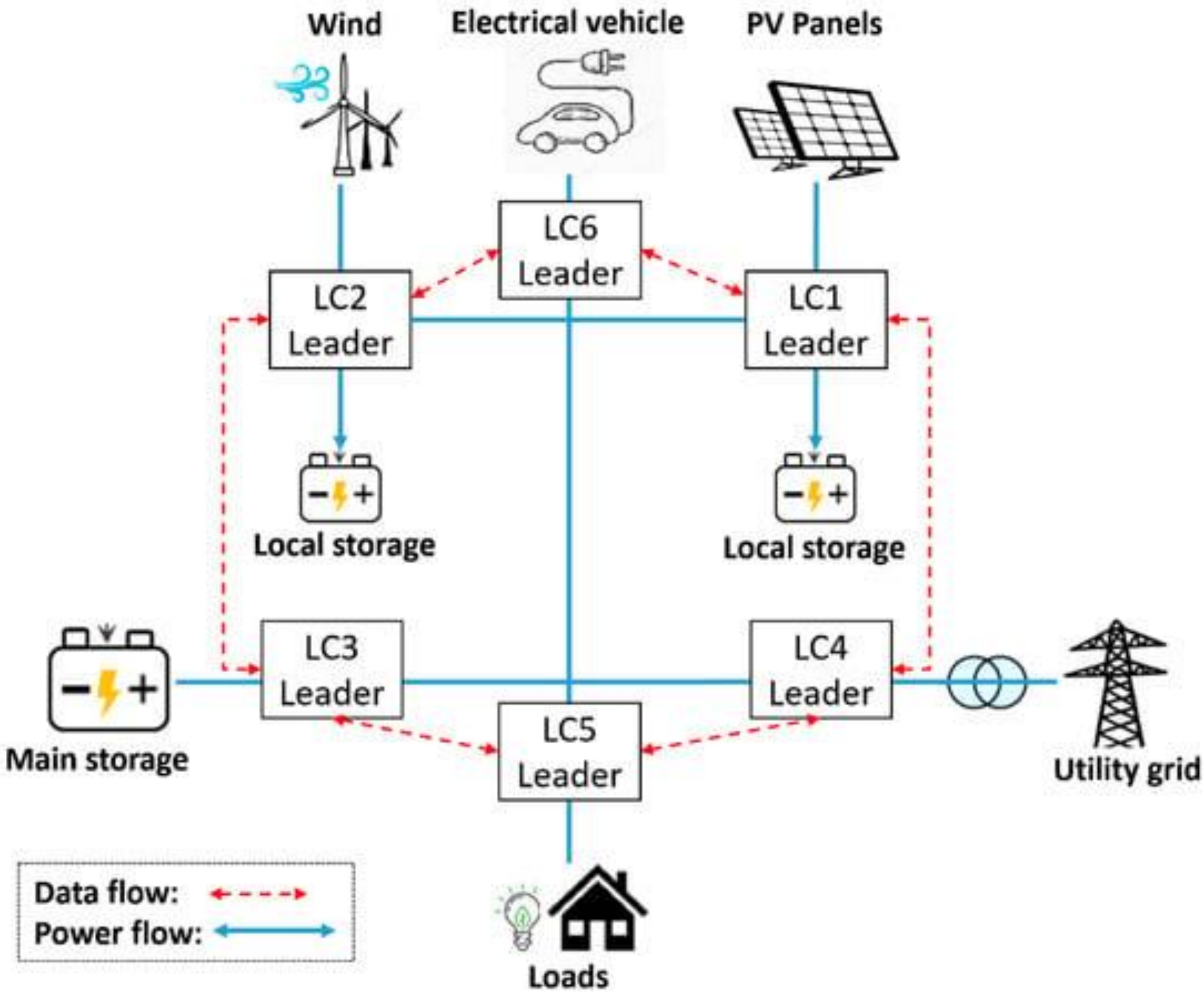
While in the partially independent mode of operation, the local controllers communicate with each other and also with the central entity

Decentralized/Distributed EMS



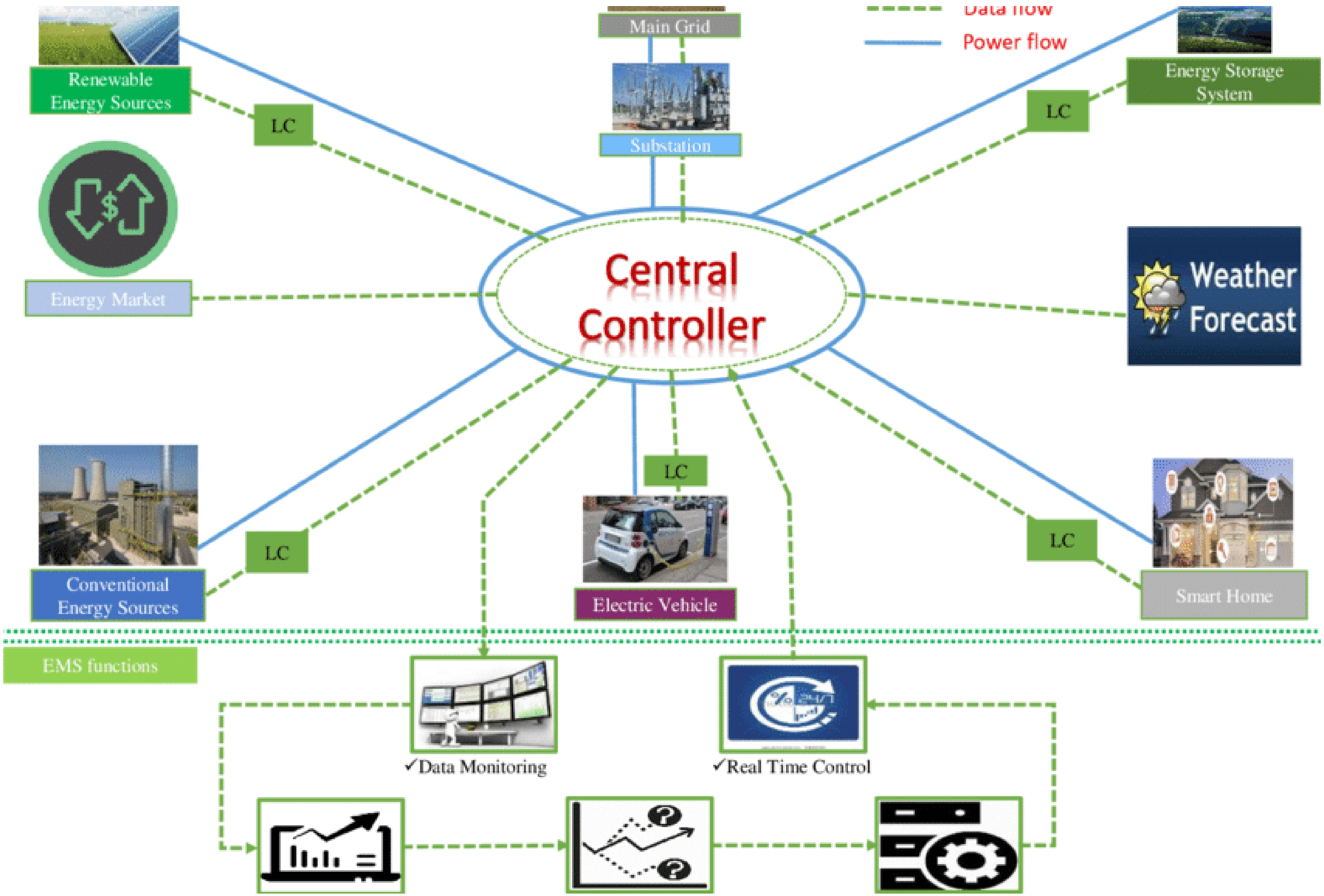
Fully dependent mode of operation

Decentralized/Distributed EMS



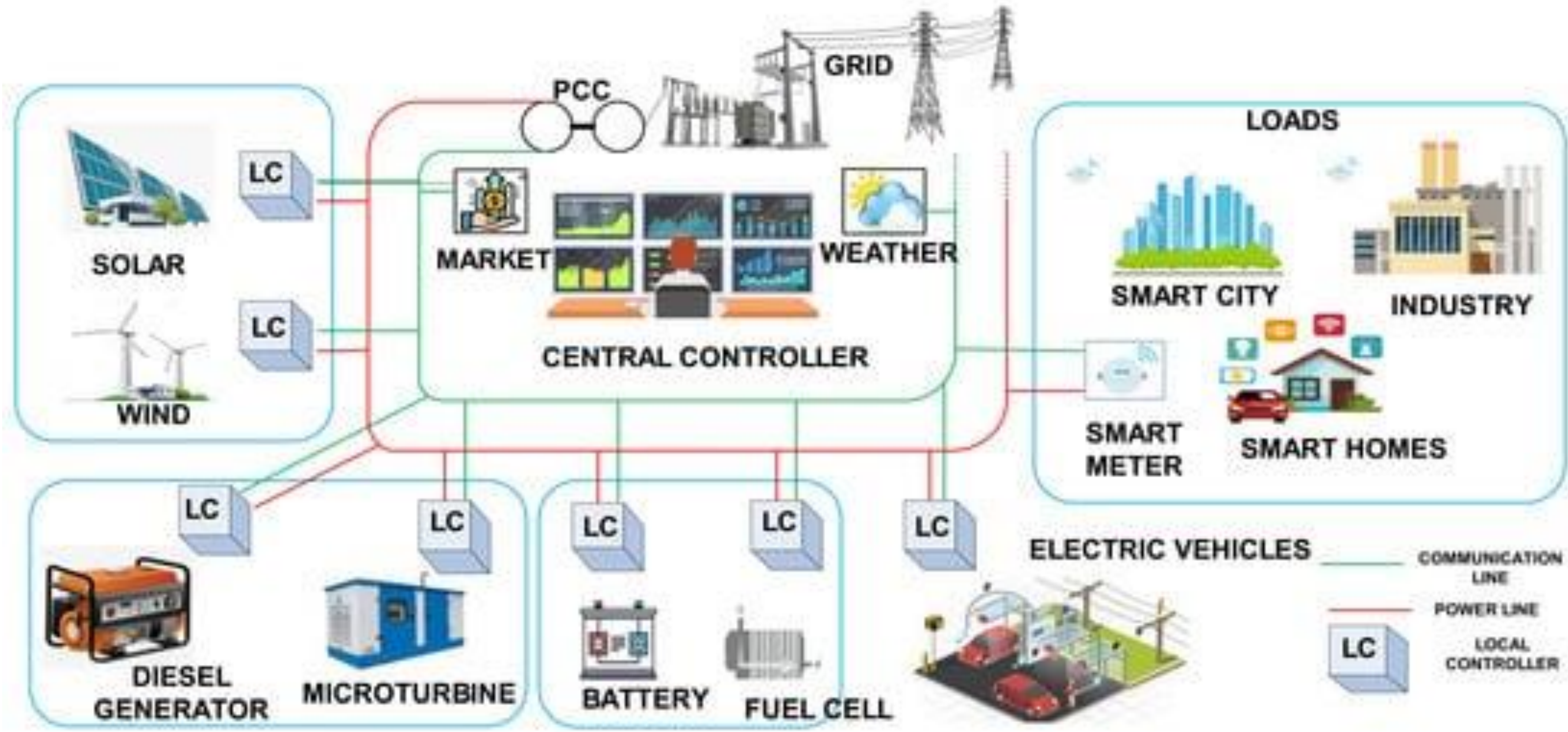
Fully independent mode of operation

Decentralized/Distributed EMS



Partially independent mode of operation

Decentralized/Distributed EMS



Partially independent mode of operation

Decentralized/Distributed EMS

Advantages of Decentralized EMS over Centralized EMS

- The redundancy of controllers and communication contribute higher reliability
- Lower computational burden
- Faster response time
- More reliability

Shortcomings of Decentralized EMS compared to Centralized EMS

- Centralized EMS provides global optimization hence provides a reduction in total operating cost
- Local optimization in decentralized EMS will not be able to provide a solution for minimization of total operating cost as a whole

Decentralized/Distributed EMS

Objective

- Operating cost optimization
- GHG emission minimization

Merit

- Provide higher privacy to consumers
- Computational burden distributed among all EMSs
- Higher flexibility

Demerit

- Needs to consider separate objectives for different LCs
- Exact optimization is not possible
- Increased total operating cost
- Effective communication system and effective synchronization is required among LCs

Hierarchical EMS

Hierarchical EMS is more applicable for Multi Micro Grid (MMG) or microgrid community (MGC) system where the individual microgrids are interconnected to form a Micro Grid Cluster (MGC)

- In hierarchical architecture, the system is divided into multiple levels of control with different control objectives at each level
- Generally, two-level or three-level structures are proposed
- The flow of information is only between adjacent levels, and no information is exchanged between units at the same level

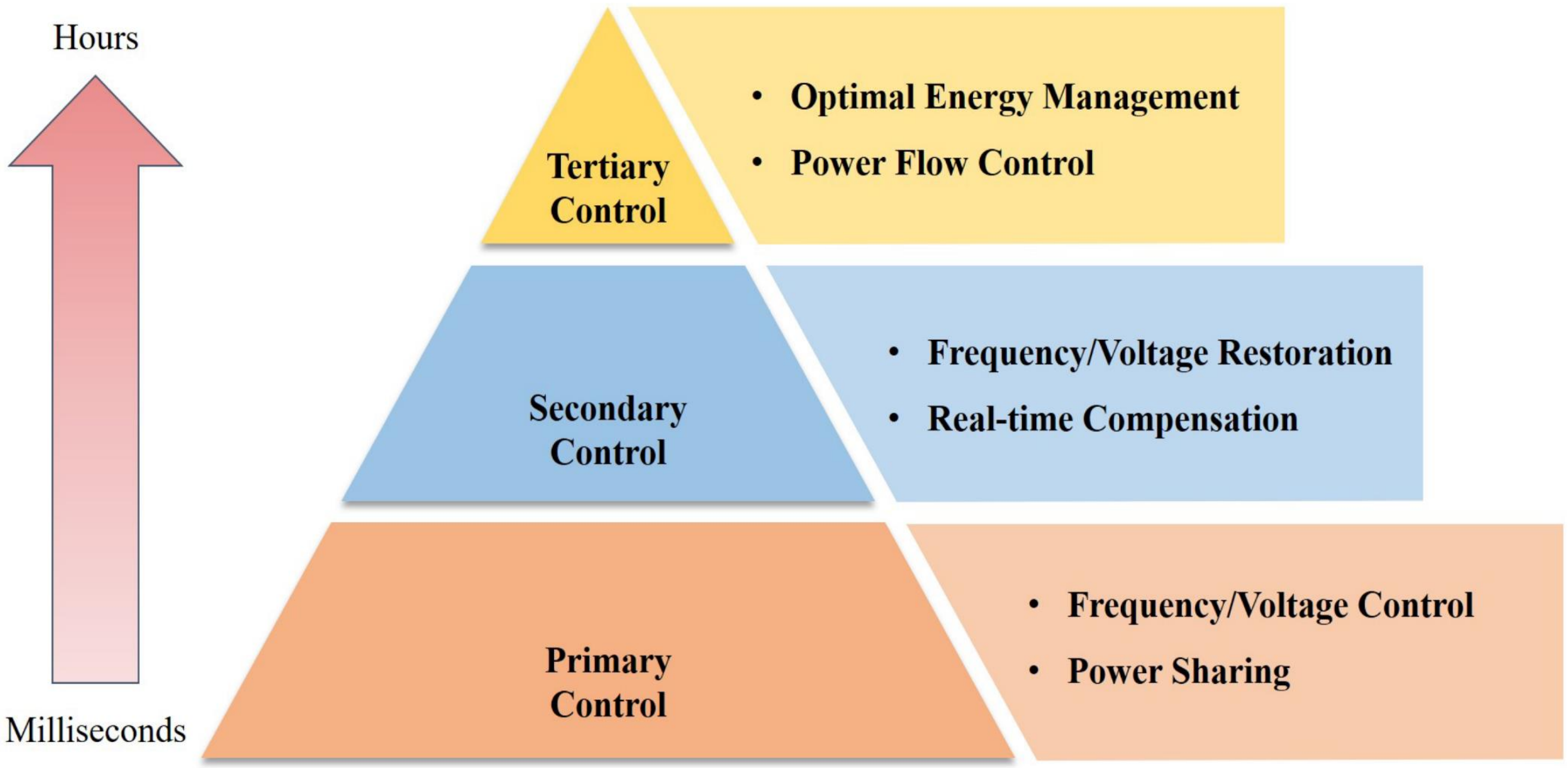
Hierarchical EMS

The upper layer performs energy scheduling

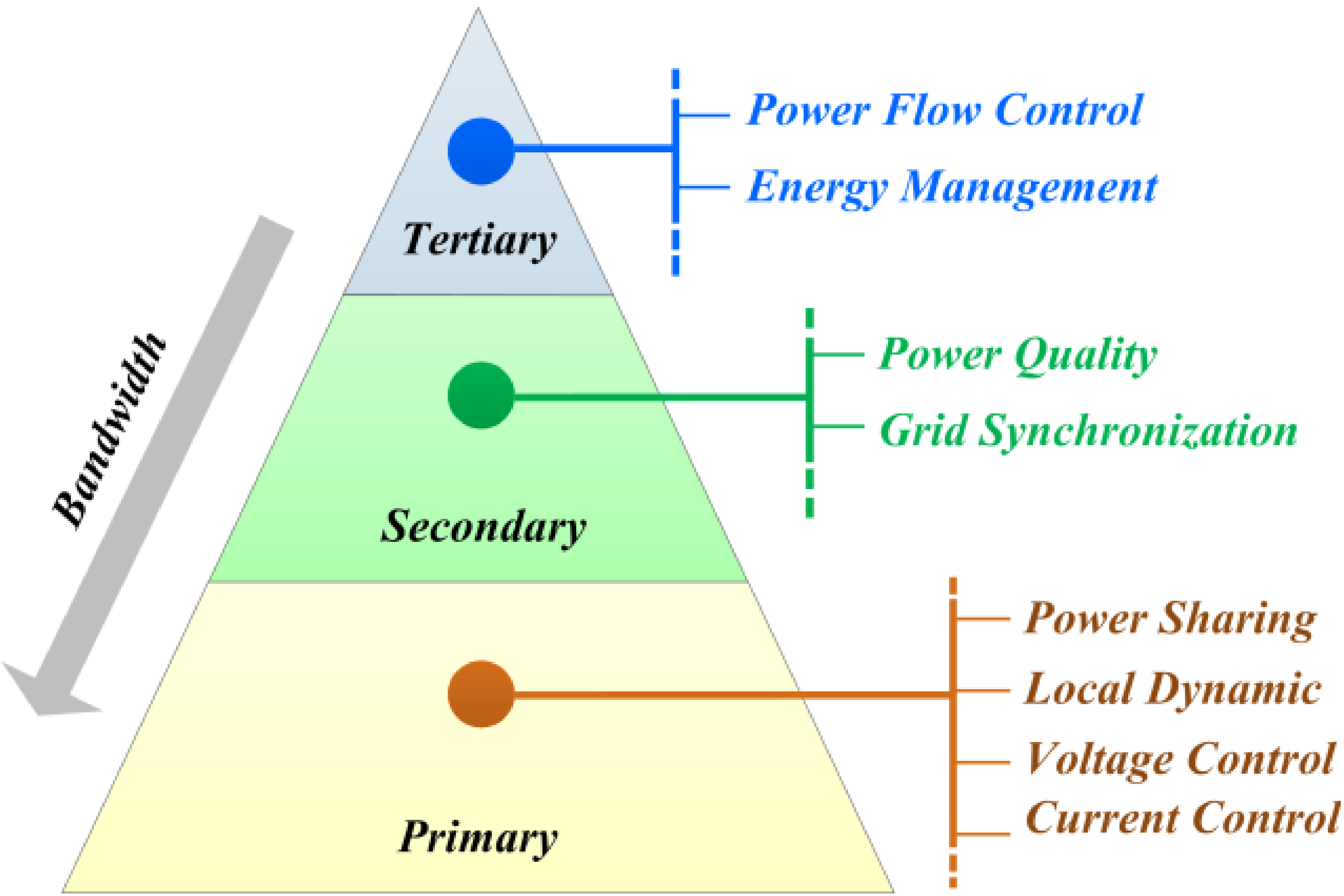
It is at this level the power is exchanged between microgrids and the main grid, and the power exchanged within the microgrids network is calculated and communicated

At a lower level, decisions are taken based on chance-constrained controllers considering various uncertainties at local/equipment level controllers

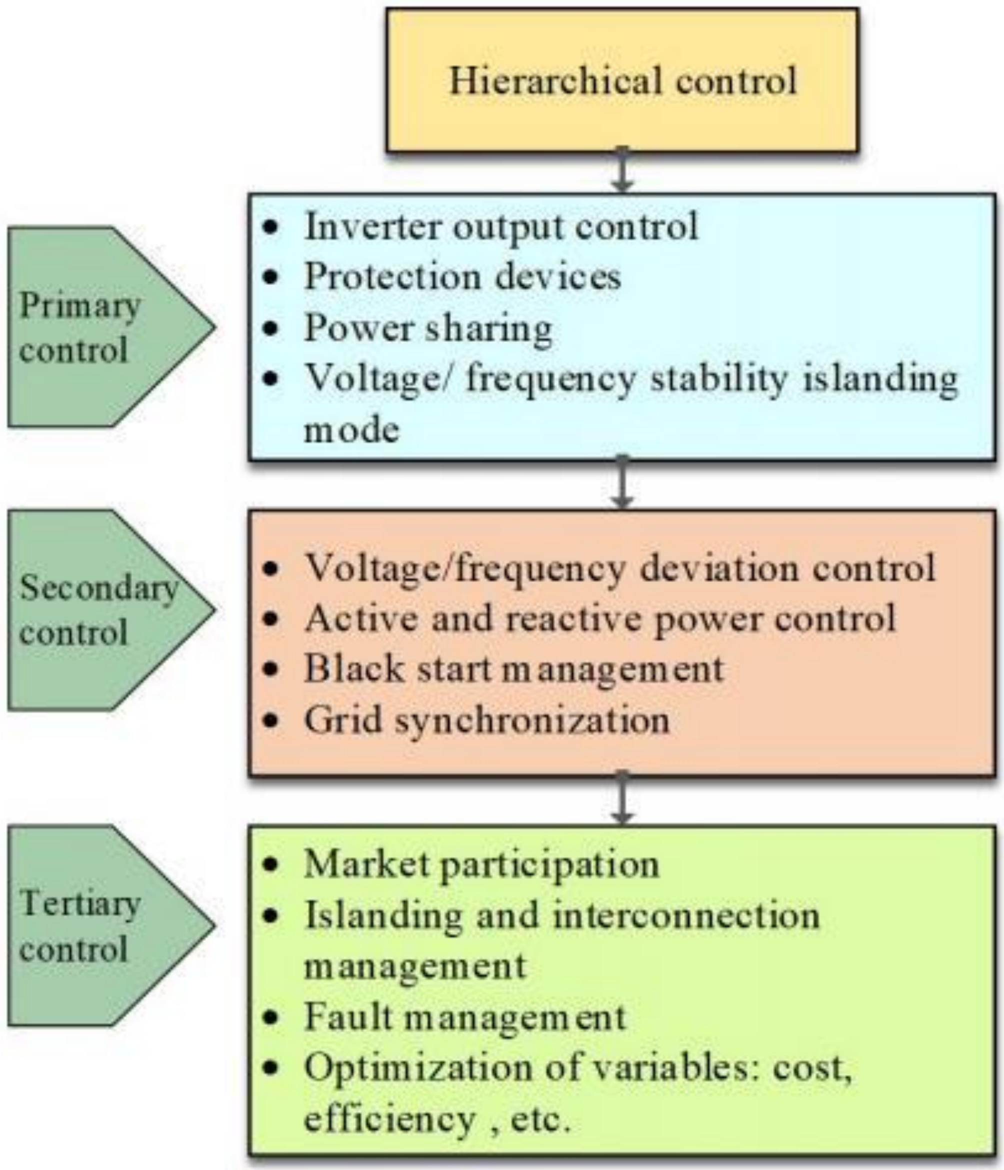
Hierarchical EMS



Hierarchical EMS



Hierarchical EMS



Hierarchical EMS

Objective

- Minimize unscheduled power exchange
- Improved transient performance
- Minimize line losses and maintain voltage
- Minimizing operating cost
- GHG emission minimization

Merit

- Layer wise control can enhance reliability and accuracy
- Best suited for multi-microgrid or microgrid community
- Both operating cost and power quality can be handled
- Higher flexibility

Demerit

- Complicated control architecture and implementation
- High level of communication requirement

EMS at Distribution Level

Since the customer is empowered and plays a key role in smart grid, EMS at the distribution level can monitor control and optimize the local system performance.

At the customer end, some of the commonly implemented EMS are:

- Smart Home Energy Management System (SHEMS)
- Home Energy Management System (HEMS)
- Building Energy Management System (BEMS)
- Plant Energy Management System (PEMS)

At the end users level, the ultimate role of EMS is to minimize energy usage by properly scheduling the devices in specified time horizons

Other types of EMS:

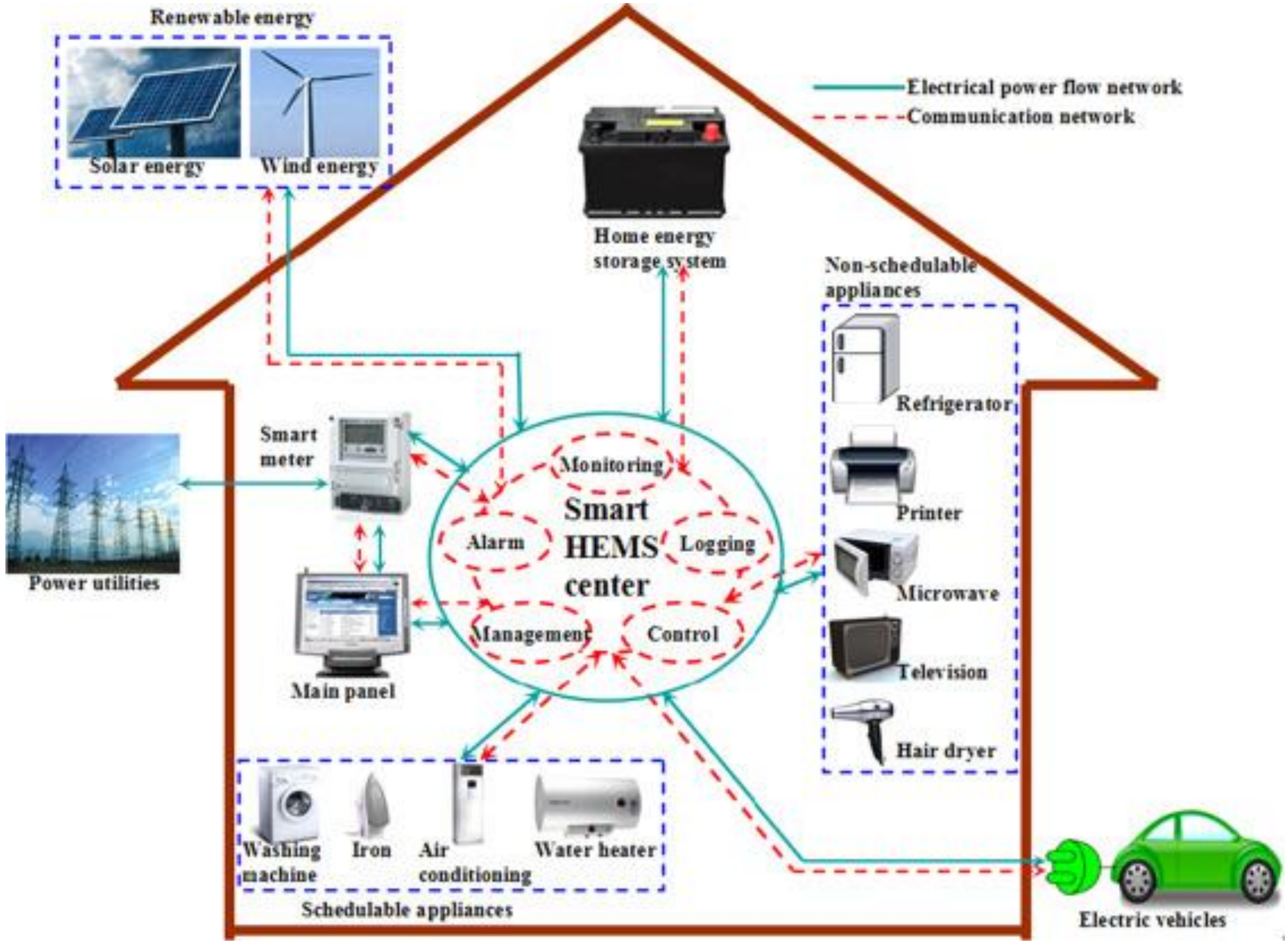
- Factory energy management system (FEMS)
- Electric vehicle EMS (EV-EMS)

Home energy management system (HEMS)

"A home energy management system is a technology platform comprising of both hardware and software that allows the user to monitor energy usage and generation and to manually control and automate the use of energy within a household"

- Optimize usage of appliances
- Minimize the electricity bill by scheduling the household appliances and ESS in response to the dynamic price of electricity
- Minimize electricity bill by considering user-defined priority-based scheduling of loads in response to real-time electricity pricing
- Efficient use of appliance load monitoring method, taking into account the comfort level of customers
- Maintain equilibrium between demand and supply by interacting with the customers

Home energy management system (HEMS)



Home energy management system (HEMS)

The residential customers are kept informed of electricity time-varying prices and have the liberty to decide their independent consumption rather than following the imposed electricity consumption

The smart microgrids can continuously interact with both the utility and the customers and adapt to changing circumstances to maintain the balance between supply and demand in a manner to benefit both customer and utility

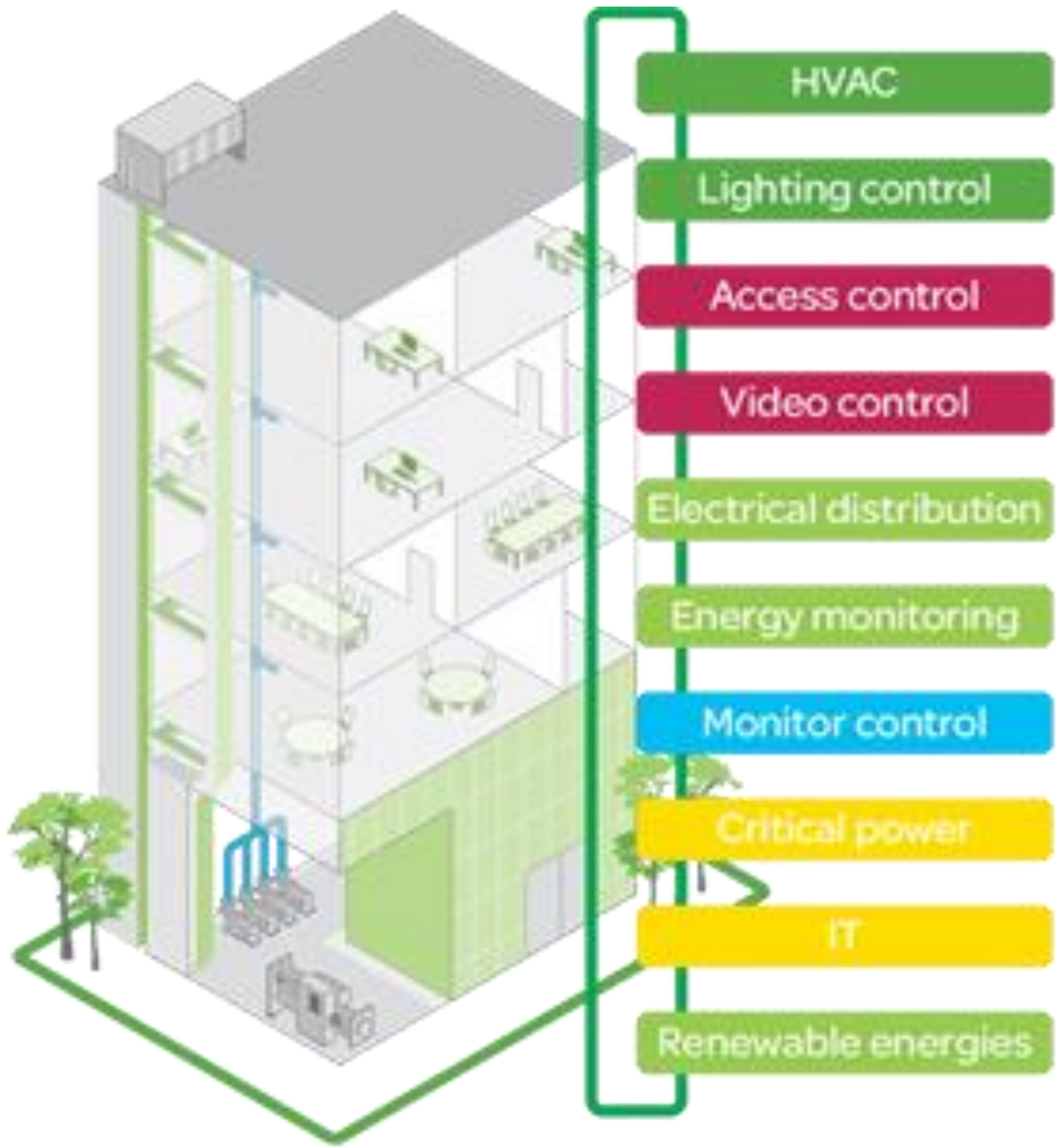
Building Energy Management System (BEMS)

BEMS can control and monitor the building energy needs to minimize the overall energy consumption, considering the comfort and convenience of the customers

Significant loads considered in BEMS modeling are HVAC, lightning, and charging loads

BEMS can be applied for commercial and residential buildings

Building Energy Management System (BEMS)



Building Energy Management System (BEMS)

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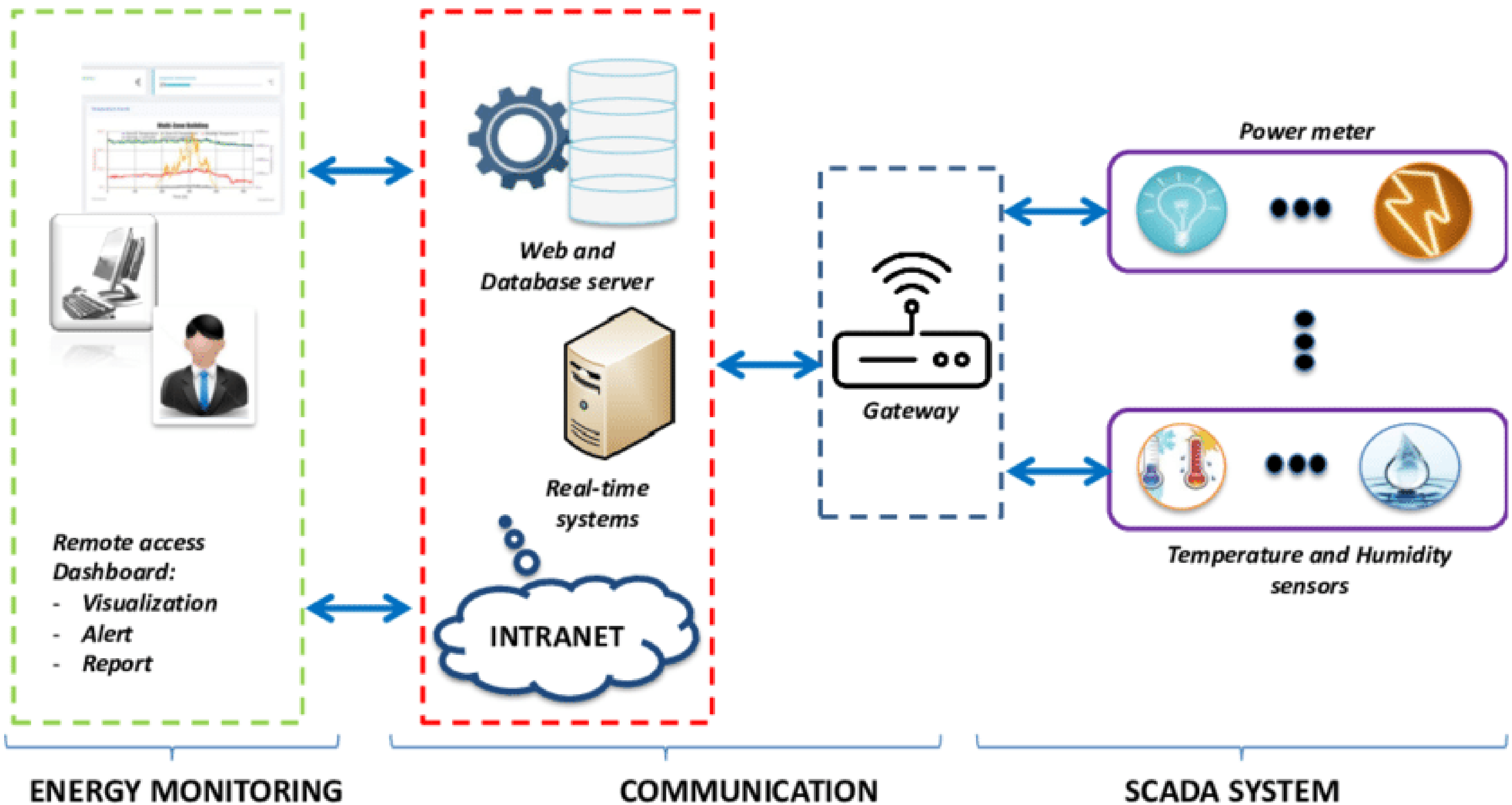


Building Energy Management System (BEMS)

A building automation and control system (BACS) is used to minimize power and energy consumption, using time-driven and the event-driven mechanism for calculating demand

Electricity demand can be modelled by extracting accurate and reliable information about the current and expected energy use

Some BEMS consists of combined heat and power (CHP), which utilize waste heat energy

Effective BEMS can result in 50% to 60% saving in total electricity cost

BEMS technique utilizes the time of use (ToU) electricity tariffs (off-peak, peak, and standard) to minimize the cost of electricity for commercial buildings

Comparing HEMS and BEMS

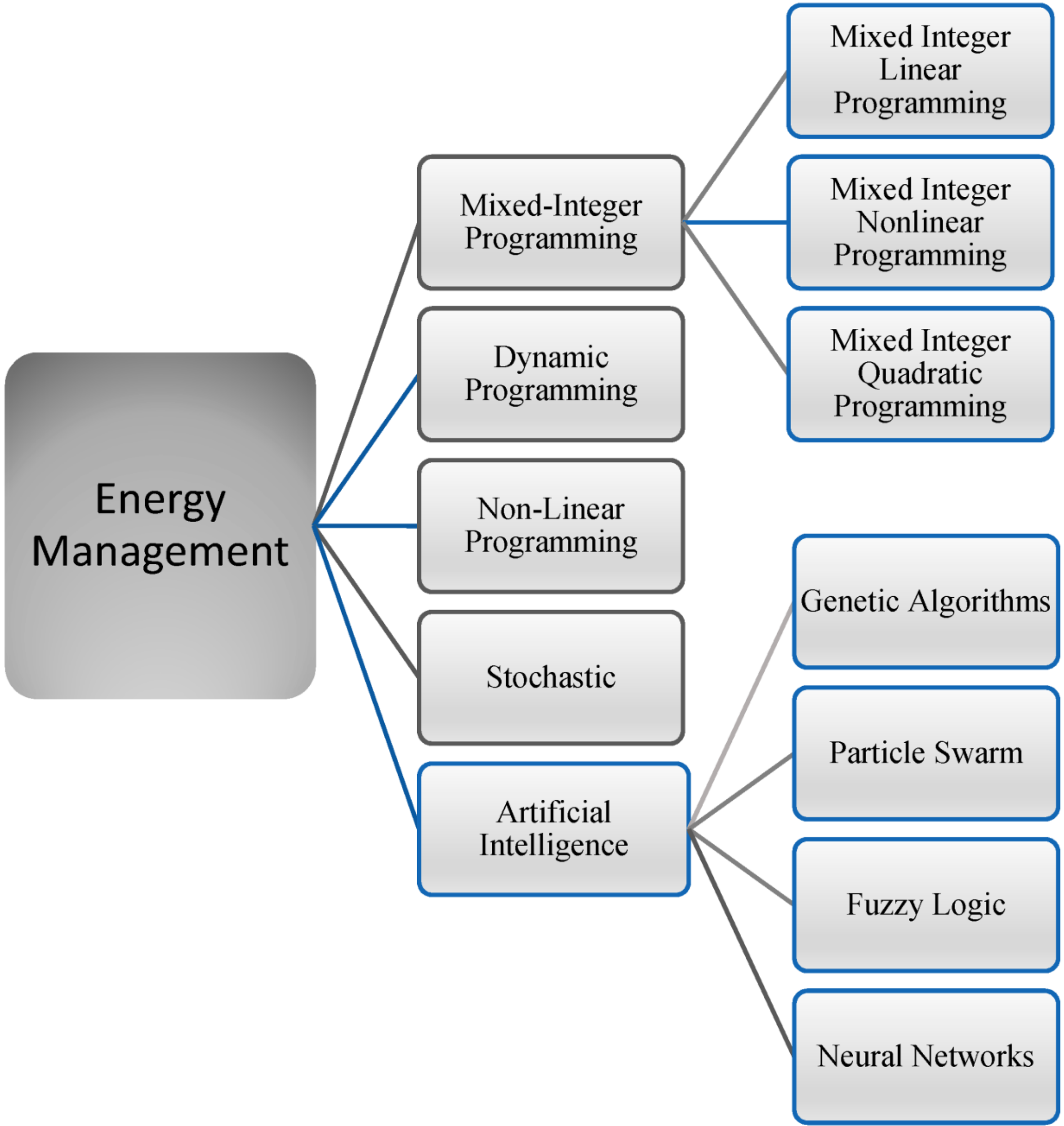
HEMS	BEMS
• Optimize home energy usage • Decision based on pricing policy and tariff • Effective DR participation • Consumer interaction and involvement in energy management and conservation	• Efficient demand control and response system • Minimize energy consumption within the building • Short-term forecast of building load • Minimize waste of heat/thermal energy

Implementation of HEMS and BEMS

The following points need to be considered for the practical implementation of HEMS and BEMS

- Computational time plays an important role and needs to be minimized by robust controllers
- The privacy of the user's data is an important concern that needs to be addressed.
- Local implementation reduces the cost of communication and links
- Comfort level of the customer should be a priority so that every end user keen to take part in such programs

Computational approaches for EMS



Real world implementation of EMS

Implementation of EMS seems relatively easy in the modern era due to advancement in communication technology, modern infrastructure, and sensors, but there are many challenges in the practical implementation of EMS

- The easiest EMS have centralized control architecture as it requires simple maintenance, but with an increase in penetration of RES, PEVs, ESSs, its computational time increases and its performance deteriorates
- The decentralized structure offers a solution, but it requires synchronization among components, and continuous two-way communication makes it less cost-effective.
- The hierarchical EMS in the area is needed to be explored further for efficient operation and control of the grid
  - In hierarchical EMS, layerwise decisions are taken and processed with consideration of multi-objective such as power quality, cost, and comfort to customers

Real world implementation of EMS

Communication is another important aspect to be considered for the real-time application of any EMS

Cost and data rate are the two factors that are considered for the deployment of EMS in residential and rural areas

Bluetooth, Wifi, and Zigbee are preferred in these areas

However, for implementation of EMS in utilities and microgrids, coverage rate along with data rate is essential, and optical network, 3G, and 4G are better choices

Real world implementation of EMS

There are many issues yet to be resolved for the practical and real-world implementation of EMS

Many simulations and case studies have been done, but only a few presented the practical and real-world implementation of EMS, whether related to building EMS, home EMS, microgrid EMS, etc.

However, in the field, several implementations of EMS have been done by big players like General Electric, ABB, Schneider, and Siemens

Still, some gaps remain between institutional developers and policy maker, and there is a strong need to bridge the gap