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Smart Micro Energy Network for Eco-Communities

The main objective of energy planning in green eco-communities is to achieve maximum urban energy efficiency, and to use clean energy, renewable energy sources and end-use energy-saving to alternate the fossil fuel energy. This paper introduced the concept of micro energy network, and presents a comprehensive analysis of the architecture and configuration for the core layer, the framework layer and the management layer, respectively. The paper introduced the new technology concepts such as smart grid, smart-grid ready heat pump, distributed heat pump systems, energy bus, and the ubiquitous control network protocol. Under existing conditions, the micro energy network technology is completely achievable and landing-available.

Keywords: green eco-community, energy planning, smart micro energy network, smart grid-ready heat pump, energy bus, ubiquitous control network protocol.

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In 2012, China's urbanization rate has reached 52.6%. At the next two or three decades, China's urbanization will be a critical period. The speed and scale of China's urbanization is unprecedented in the history of mankind. Almost all new development zones or industrial parks have developed a low-carbon eco-development planning. The special plan for energy is an important component of low-carbon eco-development planning. Differing from past supply-side energy planning for electricity, gas and heat supply network, this special energy planning is a demand-side planning, its main function is:

- Setting strategic energy efficiency goals and key performance indicators for the community.
- Integrated application of renewable energy and low-grade renewable heat.
- Take the client's energy-saving as a virtual carbon-free alternative energy resources.
- Efficient use of low-carbon natural gas fired distributed energy cogeneration.
- Achieving cascade utilization and heat recovery of fossil energy resources.
- Diversifying investments of community energy system, marketizing energy management, promoting the Clean Development Mechanism (CDM).

Concepts of the Smart Micro Energy Network (SMEN)

There are three levels of SMEN:

(1) Core layer: the on-site power generation system, such as photovoltaic, small wind turbine, fuel cells, natural gas or biomass gas fired small micro-CHP systems (combined heating & power), as the core of SMEN.

(2) Framework layer: distributed heat pumps, energy bus integrating a variety of low-grade heat source / heat sink, and thermal storage facilities as the framework of SMEN. The heat pump is an important link between Core layer and demand-side client users.

(3) Management layer: using the information and communication technologies, such as internet technology, internet of things, and cloud technology, to support interactive community energy management systems. This kind of energy management essentially is a service.

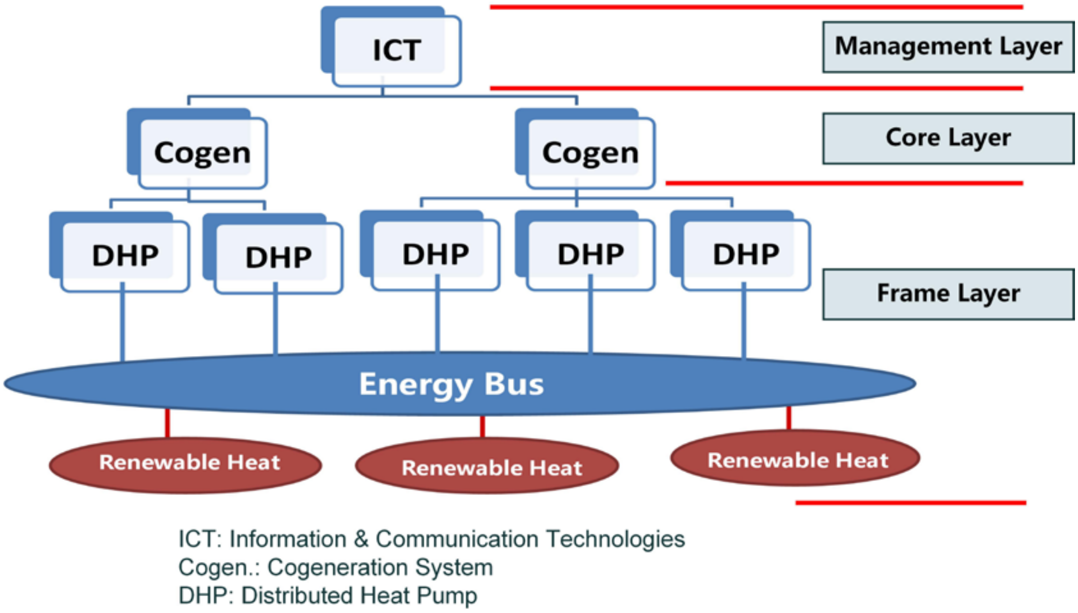

Figure 1. Three levels of Smart Micro Energy Network (SMEN).

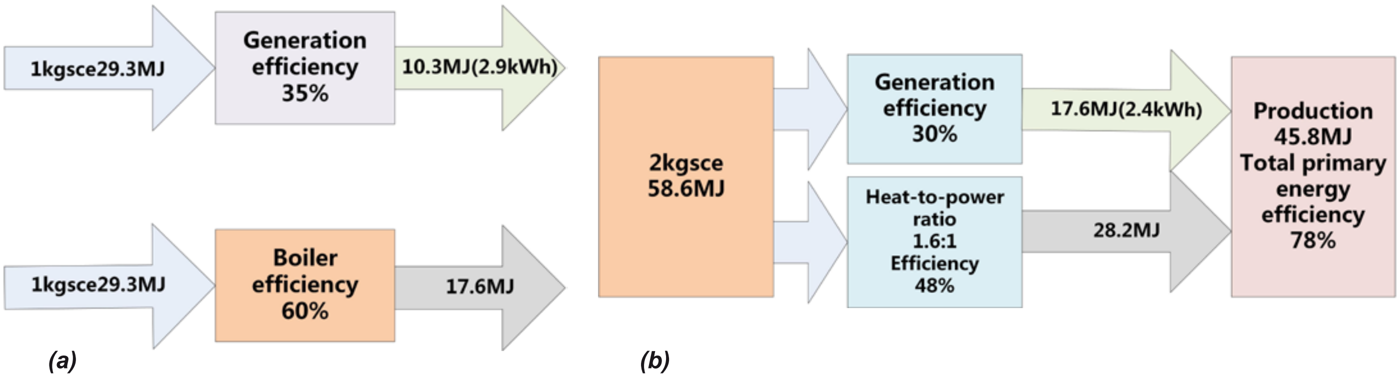

Figure 2. The efficiency of separate generation (a) and cogeneration (b).

The most important feature of on-site power generation by renewables and clean energy is its instability, especially the mismatch between supply (generation) and demand (load) and the inconsistency of the time and the power. There is another mismatch for cogeneration systems, namely heat and electricity. For building energy use in urban area, it is never to spent electricity and heat synchronously. According to the current technologies, large-scale electricity storage has not been used in commercial operation. But all cogeneration equipment has a certain heat-to-electric ratio range, if the electricity from cogeneration has neither been use up nor connected to grid, the system will shut down, and therefore to affect heat production.

Core layer of SMEN - matching between on-site generation and demand

Economic analysis

In China, the connecting of electricity from on-site distributed generation system to the grid always a policy bottleneck plagued the development of distributed energy. According to the current policy, the power from distributed energy system should be locally utilized, and could be connected to the grid at the voltage of 10 kV and below. The total installed capacity of individual plants is not allowed more than 6 MW of power. Calculating by current purchasing price of connected distributed electricity to grid and market prices of natural gas, the investors of distributed energy will be absolutely no return.

From the economic point of view, we should focus on how to play the value of electricity generated. If we just to consider connecting the electricity, the high-grade energy, to the grid, it is tantamount to sell the Mao-tai at the price of industrial alcohol.

Energy efficiency

As can be seen from **Figure 2**, because of the use of small generation power plant, power generation efficiency of the distributed energy plant is lower than the system of separate generation of heat and power, but its total efficiency can be reached up to about 80%. Its energy production efficiency is also increased by 64%.

Cogeneration of distributed energy system has prerequisites for success: ① a stable heat and electricity demand; ② heat and electricity can be all spent in a certain area. This is not difficult to achieve for traditional manufacturing demand. But in urban communities the client-users are building heating and cooling. If only consider to use the heat from cogeneration but ignore how to use the electricity, it actually reduces the efficiency. Because the most efficient heating device is condensing boiler (above 90% efficiency), while the most efficient natural gas combined cycle power generation technology (above 50% efficiency). Integrated thermal efficiency and power generation efficiency of all DES (distributed energy system) technologies are impossible to higher than the two techniques. Thus, if only for the purpose of building heating and cooling, it is no necessary to use cogeneration systems with investment.

But cogeneration can mainly generate electricity, while electricity is high-grade energy. It cannot simply be measured by thermal efficiency. For cooling and heating of buildings, the electric driven heat pump can be used. Also the absorption heat pump can be used to improve thermal efficiency.

The most high efficiency heat pump is that with Magnetic Bearing Chillers (MBC). The COP of MBC is 6.3 on cooling mode and 5.6 on heating mode (with water temperature up to 60°C). Normally the COP of absorption heat pump can reach to 1.6 ~ 2.4 (with LiBr refrigerant and water absorbent).

Using MBC heat pump and absorption heat pump to combine cogeneration, the energy efficiency can be very high. As shown in **Figure 3(a)**, the primary energy efficiency of the heating system with absorption and electric-driven heat pump can reach to 232%. In the hot summer and cold winter zone and hot summer and warm winter zone in China the cooling load is dominated. Thus the system configuration should be depended on winter heating load. The lack of cooling load in summer could be undertaken by electric-driven magnetic bearing centrifugal chillers connected to the grid (see **Figure 3(b)**). The primary energy efficiency of the cogeneration system can achieve 250% (or 260% if the heat is included), and the total system efficiency can reach to 254%.

The progress of cogeneration + heat pump system configuration (as shown in **Figure 4**) includes three steps:

(1) To determine the type of prime mover and heat pump. To draw energy flow chart. To calculate the system integrated thermal efficiency.
(2) According to the building heating/cooling load and the system integrated thermal efficiency, to calculate the fuel requirements to be provided to the prime mover.
(3) According to the thermal efficiency of the prime mover, to determine the system's power generation and size of generators.

Frame layer of SMEN - the energy bus integrating low-grad renewable heat sources

From the viewpoint of the energy balance, the heat produced by electric-driven heat pump composed by two parts:

(1) Drive energy (electricity);
(2) Ambient energy (air, surface water, soil, ground water, sewage etc.);

Since the grade of ambient energy (temperature) was lower, it must be consumed some high-grade energy (such as electricity) to increase the temperature. While the ambient energy consists of two parts, namely:

(1) Recovery of heat extraction from thermal power plant;
(2) Low grade renewable heat source.

It can continually maintain the heat pump running at higher efficiency, to find a suitable and stable supply of renewable heat. If the power generation efficiency is 35%, and the COP of air-source heat pump is 2.6, then the primary energy efficiency of the heat pump system is only 90%, just same as the efficiency of a gas boilers.

Energy Bus system is a pipe network system that will integrate multiple renewable heat source or heat sink, transport water through a pipe network (as infrastructure of community) to distributed water source heat pumps.

Due to use of multi-source multi-sink, it can adopt good points and avoid shortcomings of various source/sink. For example, in eastern China, the temperature of surface water is lower in winter, the soil coupling

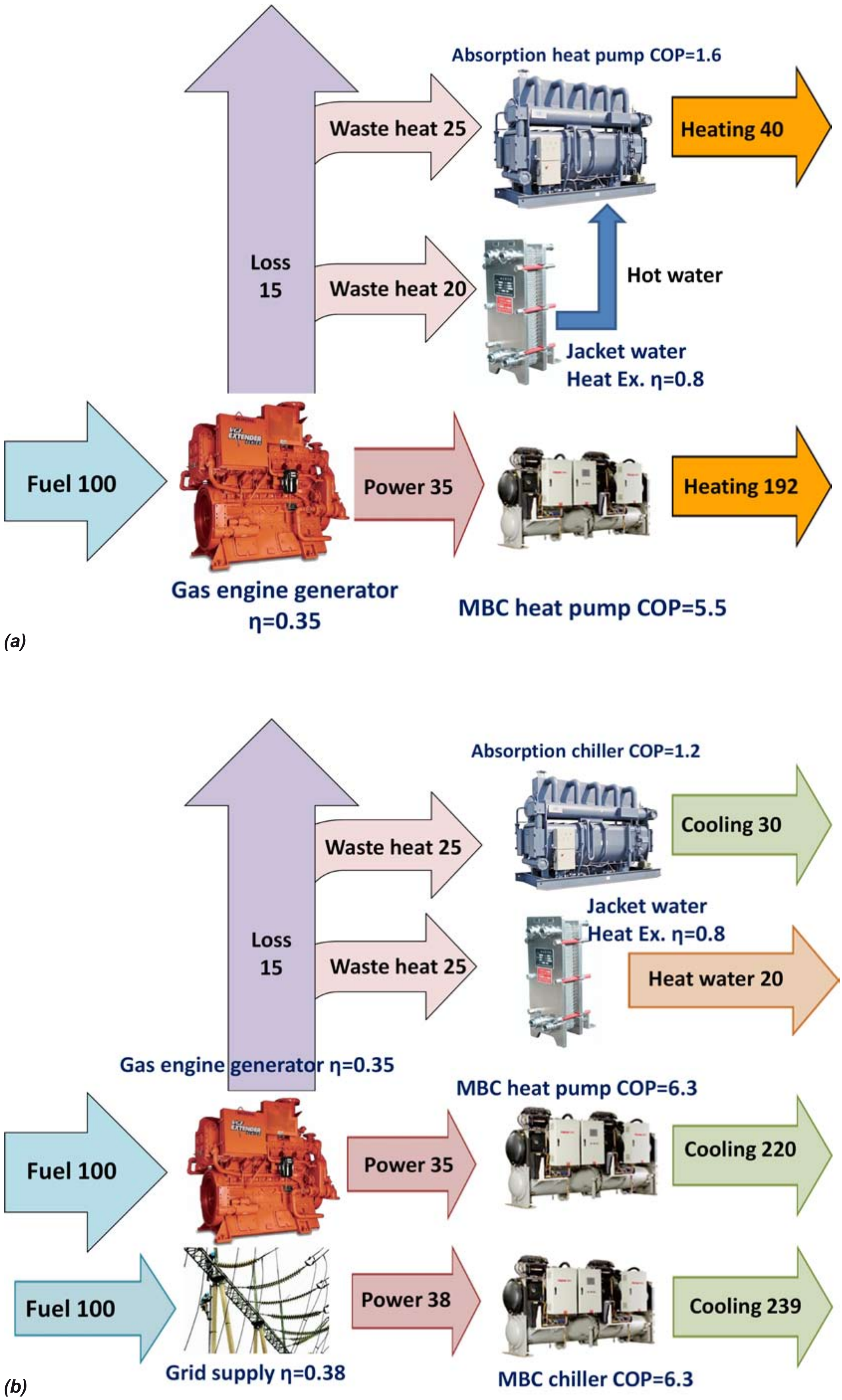

Figure 3. Relative energy flow in heating mode (a) and cooling mode (b) for cogeneration plus heat pump system.

heat exchanger should be a main heat source. While in summer, the surface water or even cooling tower could be as the auxiliary heat sink. According to the cooling load profile it can be considered that the cooling towers bear base load, the surface water bears intermediate load, and soil coupled heat exchangers bear peak load. Thereby the heat accumulation in soil can be avoided, and giving "breathing" time to soil.

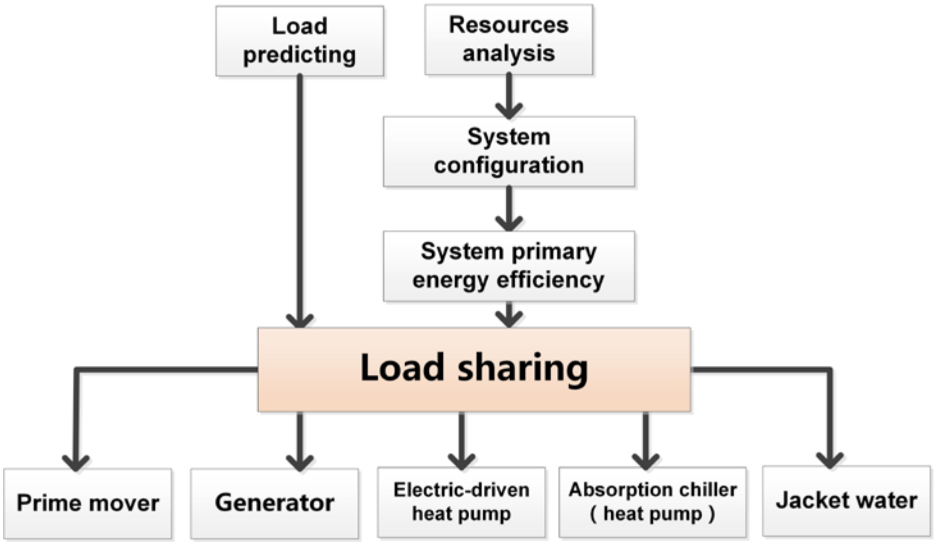

Figure 4. Program of system configuration.

If the modular energy stations with magnetic centrifugal heat pump are configured to end users, the system will have a high energy efficiency. Moreover, the share of the cooling tower in energy bus system and the use of natural water sources make the exergy loss of energy bus are also lower than that single building conventional cooling systems.

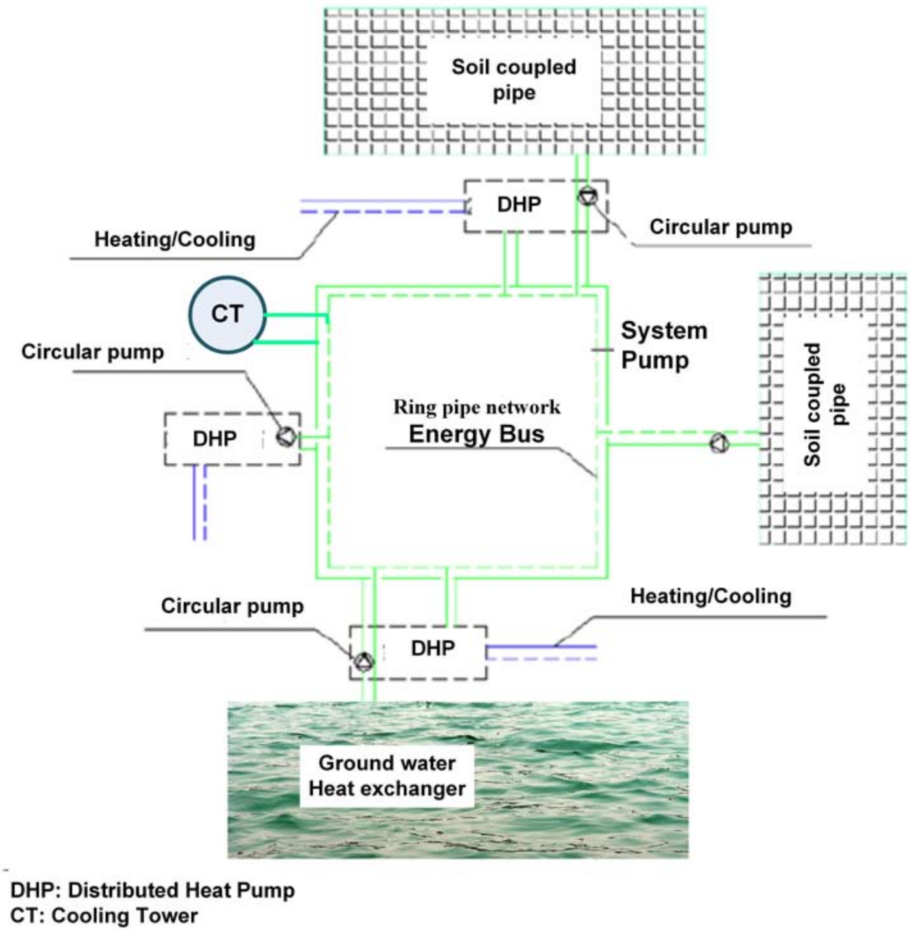

Figure 5. Schematic diagram of community energy bus.

Management layer of SME - the EMS based on Ubiquitous Control Network Protocol

With the "heart (core)", and with the "skeleton (framework)", then we need to have a "brain". In the past, only have monitoring systems on the level of urban communities. It is difficult to establish a unified control system. This is mainly because for various brands of equipment and various types of systems they have their own different control protocol. It is currently known as LonWorks, ModBus and BACnet, which are mainstream system.

In 2011, approving by the U.S. Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA), the IEEE1888 standard (Ubiquitous Green Community Control Network Protocol) which has been prepared under leading of a Chinese enterprise, has offi-

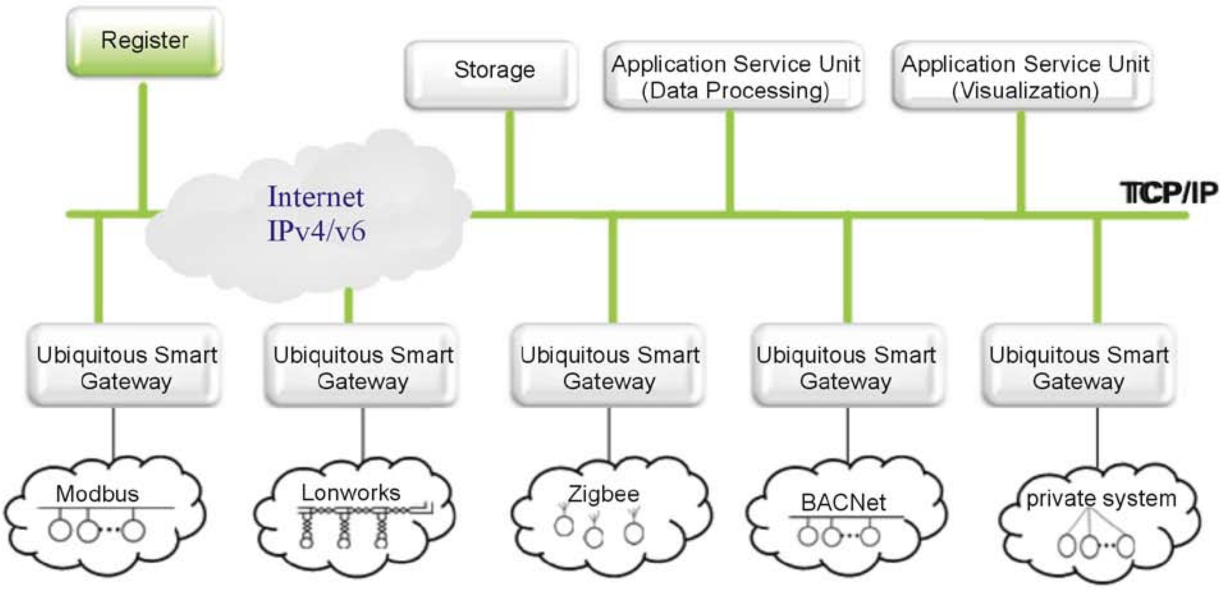

Figure 6. Systematic network architecture of IEEE 1888.
(From BII Group Holdings Ltd. http://www.biigroup.com/en/jishubiaozhun.asp?ArticleID=614)

cially released. This is a functional network architecture in order to achieve the purpose of green community and energy saving, based on Internet technology (TCP/IPv6), via a remote network and sensor networking, to achieve unified management and intelligent control of energy facilities within the community. The purpose is to achieve energy efficiency and rational use. IEEE1888 is compatible with BACnet, LonWorks and ModBus, and other industrial control protocol.

Ubiquitous control network protocol becomes the basis for constructing community energy management systems. The SMEN management system should achieve the following control functions on a uniform platform:

(1) Power dispatching at core level;
(2) Heat storage control;
(3) Clients' electrical energy production and marketing control, metering and billing;
(4) Energy Bus source / sink coordination control;
(5) Energy-bus pipework control;
(6) Operation management of energy plant;
(7) Clients' consumption of heating and cooling metering and billing;
(8) Community energy consumption monitoring, statistics and analysis;
(9) System diagnostics;
(10) Real-time demonstration of energy system operating and efficiency.

Conclusion

Using SMEN, two goals can be achieved: first, to improve the energy efficiency of high-grade fossil energy with cascade utilization; second, to improve the utilization ratio of low-grade renewable energy (or renewable heat). In the progress of rapid urbanization in China, the SMEN will have a good development prospects. ■

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