Correlation Between Energy and Information

C. C. Chan [1] and Linni Jian [2]

[1] *Department of Electrical & Electronic Engineering, The University of Hong Kong, ccchan@eee.hku.hk*
[2] *Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, ln.jian@siat.ac.cn*

Abstract

Since the industrial revolution happened in the middle of 18th century, both the thermal equilibrium and ecological equilibrium of earth environment have been broken. The skyrocketing energy consumption and greenhouse gases emission are threatening the sustainable development of human beings. The only way out is to build up new energy structure. However, the new energy structure cannot be effectively built without the integration with the information. This paper proposes a correlation between Energy and Information. The paper begins with the introduction of the features of emerging new energy structure, namely, diversity of energy sources and diversity of energy flows. Then, essential roles of energy storage in new energy structure are identified. It is believed that energy storage is able to enhance the efficiency, cleanness, reliability and stability of whole energy system. To make energy storage systems function effectively, the key issue is to integrate information into energy. The purpose of this paper is to point out this uttermost importance of the correlation between energy and information in redirecting our way to sustainable development. The proposed correlation between Energy and Information is a fundamental principle that we should pay more attention, particularly in the current big data age. The understanding of the correlation between Energy and Information will promote both the sustainable energy and sustainable information.

Keywords

energy storage, global warming, integration of energy and information, new energy structure, timeline of energy and information

1. INTRODUCTION

Energy and environment are the bases on which human beings live. It is well known that the original source of all energy is the sun. For most of the time since Homo Sapiens has reached modernity about 200,000 years ago, the environment on earth had been keeping in the so-called thermal equilibrium (Sayre, 2010), which means the high-grade energy captured by earth from the sun is equivalently matched with the low-grade heat leaving earth by black body radiation. There was once a perfect balance between energy entering the earth and energy leaving the earth. Correspondingly, the environment, the ecosystem had been maintaining good ecological equilibrium. All the resources human beings extracted from the nature are organic and biodegradable. After decomposition, they finally go back to earth, and re-fertilize the environment. All the energy forms consumed are renewable, such as wind, water, sunlight and firewood. There are no or very few exhaust emissions.

Nevertheless, these balances have been broken since the industrial revolution happened in the middle of 18th century (Ashton, 1948). It marks the major turning point in the history of humans' consumption of energy and humans' relationship with environment. With the invention of steam engine, every aspect of human life and lifestyles was dramatically changed. Manual labor was replaced by machineries, while, these machineries are mostly fed by fossil energies, such as coal, oil, and nature gas. These fossil fuels are non-renewable, what is more, burning them can produce huge amount of exhaust emissions, including carbon dioxide, nitrous oxide, methane and so forth. On one hand, these gases break the ecological equilibrium, harm and pollute our environment. On the other hand, they break the thermal equilibrium due to that they can absorb infrared radiation and hamper heat leaving the earth. That is why they are also named as greenhouse gases (Karl and Trenberth, 2003). The second industrial revolution symbolized by the advent of electrification and mass production begins at the latter half of the 19th century (Smil, 2005). It brought the world into an even more energy-intensive industrial civilization. Human beings are further more released from heavy manual work. People's life becomes easier and more prosperous which naturally result in the explosion of world population. All this are responsible for the skyrocketing energy consumption in the 20th century. The energy consumption in the year of 2000 went up 16 times compared with that in the year of 1900 (Nakicenovic et al., 1998).

Increasing fossil energy consumption leads to increasing greenhouse gases emission. Today, we have to take a serious look at two issues, energy crisis and global warming, since they are threatening the sustainable development of human beings. It seems we are rushing to where we may end up, and the only way out is to change the direction. It is pleased to see the new structure of energy is emerging recently, which aims to reduce the consumption of fossil fuels and rely more on renewable energy once again. This brings new challenges to the current power systems and energy systems, due to the stochasticity and uncertainty of renewable electrical power and energy. The energy storage may play an essential role in solving these challenges. More importantly, to make energy storage systems function effectively, the key issue is to integrate information into energy. The purpose of this paper is to point out this uttermost importance of the correlation between Energy and Information in redirecting our way to sustainable development.

2. CHARACTERS OF EMERGING NEW STRUCTURE OF ENERGY

The energy consumption had tremendously increased during the past 200 years, and it is predicted to be even higher energy consumption in the future. Population growth is one of the key drivers responsible for this. Based on the report issued by United Nations Population Division (United Nations, 2010), the world population is predicted to grow from around 6.8 billion in 2009 to about 8.6 billion in 2035 with an average rate of increase of 0.9 % per year. At the same time, according to the report of International Energy Agency (IEA), the global energy demand is estimated to increase by 40 %, from 12132 Mtoe in 2009 to 16961 Mtoe in 2034, and the energy-related greenhouse gas emissions increases by 33 %, even under the new policies scenario in which recent government policy commitments are assumed to be implemented in a cautious manner. This may lead to a long-term global temperature increase of more than 3.5 °C, which would have severe consequences: a sea level rise of up to 2 meters will cause human settlements dislocation and extreme climates such as drought, flood and heat-wave incidence. All this would severely affect food production, human disease and mortality (International Energy Agency, 2011).

In the 2011 Durban World Climate Conference, a consensus was reached: for keeping sustainable development of human beings, the average global temperature rise should be kept below 2 °C. In order to fulfill such an ambition, IEA proposed the “450 scenario” (International Energy Agency, 2010). The core proposition is to significantly reduce the shares of fossil fuels: share of coal from 27 % in 2009 to 16 % in 2035, share of oil from 33 % in 2009 to 25 % in 2035, and dramatically increase the share of renewable energy, from 1 % in 2009 to 8 % in 2035. For achieving this, the future new structure of energy should be with the characters of diversity of energy sources as well as the diversity of energy flows. Figure 1 shows the world primary energy demand shares in the year of 2009 and 2035 under the “450 scenario”. Nowadays, we mainly lie on dirty energy sources, such as coal, oil and natural gas. Hopefully in the future, the shares of clean energy sources could dramatically go up. The “other renewables” given in Figure 1 include wave energy, wind energy, solar energy, geothermal energy, modern biomass energy (Goldemberg and Coelho, 2004) as shown in Figure 2. Other more renewables are eagerly to be discovered to augment the diversity of energy sources. It is not just the matter of “not putting all eggs into one basket”, it is also the matter about diluting the possible negative effects of some energy sources.

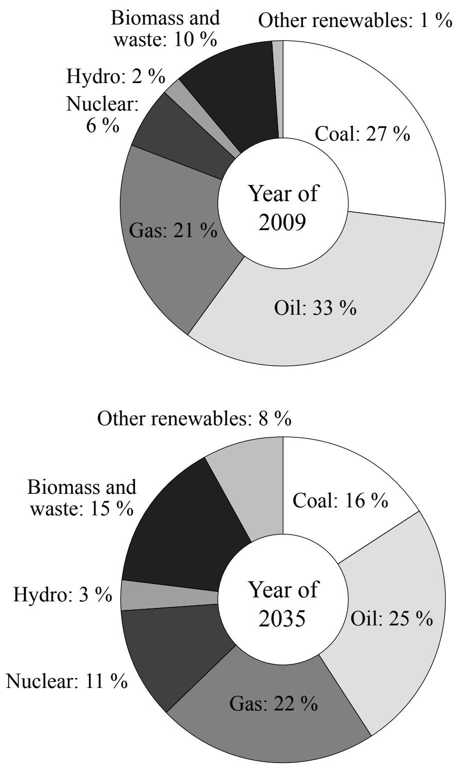

Fig. 1 World primary energy demand shares

The diversity of energy flow is another key point concerning future new energy structure. Nowadays, electrical power is the most important secondary energy carrier. As shown in Figure 2, all the renewable primary energy sources are converted to electricity, and then transmitted and distributed by the power grid. However, there may be some other possible flow paths for these renewable energy sources. As shown in Figure 3, renewable energies may be used to produce

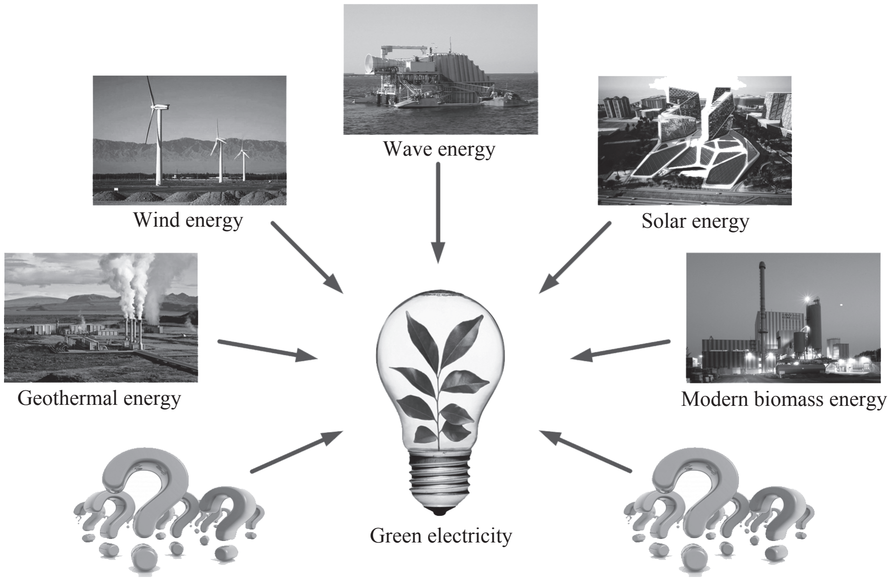

Fig. 2 Typical renewable energy sources

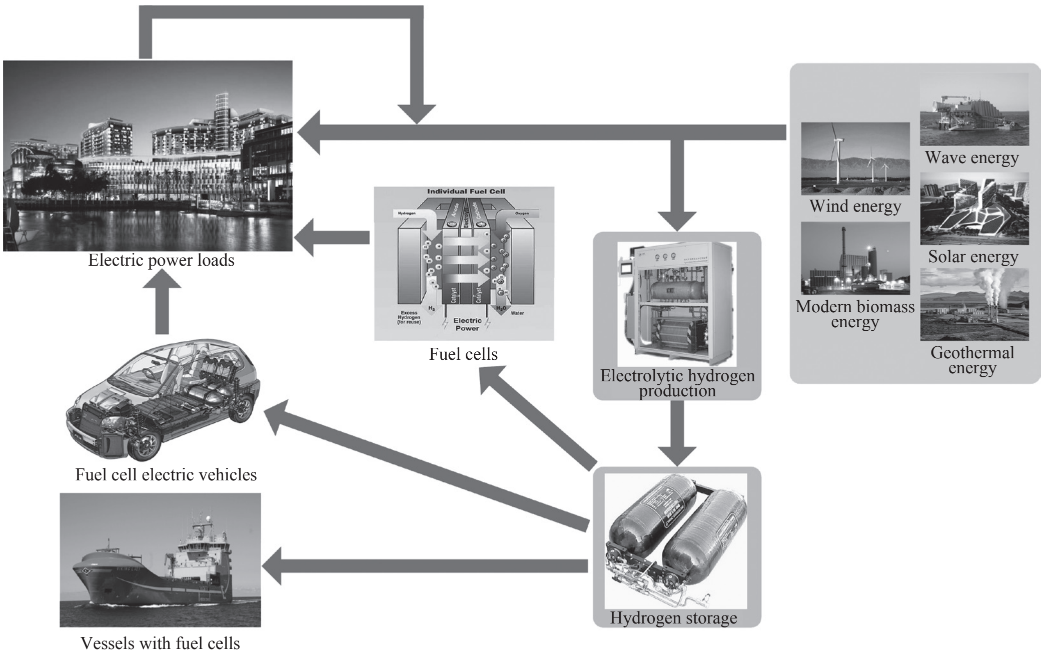

Fig. 3 Diversity of energy flow

hydrogen by electrolyzing water. Hydrogen could become another important energy carrier, providing power for the transportation, such as fuel cell electric vehicles and fuel cell vessels (Singhal, 2000). It can also directly supply electric power to distributed power grid (Teodorescu et al., 2006) by using full cell stacks. In return, fuel cell electric vehicles can supply power to other electric power loads during their parking periods. Within the scheme of smart grid (Li et al., 2010) the bi-directional electrical power flow become possible, for example, consumers can sell the renewable electricity converted from their rooftop photovoltaic panels or yard-standing wind turbines back to the power grid.

In summary, the diversity of energy source improves the sustainability of energy, and the diversity of energy flow maximizes the overall efficiency of energy utilization. Nevertheless, these can also cause serious challenges to existing power grid. In traditional power system, the deterministic part dominates in both the power generation and power demand; hence the traditional thermo power plant is well controllable. Thus, generation follows load can be conveniently achieved. With the adding of renewable energy sources and the new electric loads, such as the plug-in electric vehicles (Kiviluoma and Meibom, 2011), both the power generation side and the power demand side become more stochastic, and the renewable power generation is much less controllable since it is determined by the weather conditions. In order to achieve dynamic balance between power generation and power load, energy storages have to be engaged.

3. ROLES OF ENERGY STORAGE IN EMERGING NEW ENERGY STRUCTURE

There are various energy storage types. The pumped storage scheme and battery energy storage are among those commonly used. The pumped storage scheme stores energy by pumping water from a lower elevation into a reservoir at higher elevation. When the water is released, it goes through the turbine to produce electric power. Pumped storage is currently the largest-capacity form of electric energy storage available (Levine, 2007). Battery energy storage operates by converting electric energy into chemical energy. There are different types of batteries, such as lead-acid, nickel-cadmium (NiCad), nickel-metal hydride (Ni-MH), lithium-ion (Li-ion), sodium/sulfur (Na/S), zinc/bromine (Zn/Br), and so forth. The most recently developed Lithium Titanate Oxide (LTO) batteries showed the most promising candidate of energy storage scheme. This is due to that LTO batteries have some ten times higher cycle life and charge/discharge rate as compared with that of traditional lithium ferrous phosphate or lithium magnesium batteries. The LTO energy storage system not only can storage the electrical energy, but also performs the voltage control and frequency control of the power system due to its fast response capability. As compared with the pump storage scheme, although the initial investment cost of the LTO energy storage system is higher, but the conversion efficiency, annual usage time and construction cost are all lower. Moreover, pumped storage scheme is restricted the geographical condition and only suitable for power companies, while the LTO energy storage system no geographical condition restriction thus not only suitable for power companies but also suitable for industrial and building energy storage applications (Altairnano, 2012). The capacitor storage stores electric energy as electrostatic charges. Charge carries, typically electrons, are removed from one metal plate and deposited on another. By improving the mechanism of charge separation, the ultracapacitors can store significantly more electric energy than conventional capacitors. Compressed air energy storage stores electric energy by compressing air, and releasing the compressed air to drive combustion turbine generator to convert the stored energy back to electric energy. Flywheel storage converts electric energy into kinetic energy of the high-speed rotating flywheel. The stored kinetic energy is converted back to electric energy via the generator by slowing down the flywheel's rotational speed. Superconducting energy storage stores electric energy in the magnetic field excited by direct currents flowing in the superconducting coils. Due to the zero resistance of superconducting material, the direct current in coil can be very large, and it will not degrade. Thermal energy storage can be generally defined as storage of thermal energy at high or low temperatures. It includes three main modes, sensible heat storage, latent heat storage and bond energy storage (Ercan, 2006). Sensible heat storage does not concern phase change of storage medium, while the others undergo phase changes.

The essential roles of energy storage in emerging new energy structure generally lies in five aspects, including renewable energy integration, electric energy supply, ancillary services, electric power transmission, and end customer applications (Eyer, 2012). For the aspect of renewable energy integration, energy storage can be applied to time-shift renewable energy supply and firm renewable energy capacity. Renewable energies are intermittent electrical energy suppliers since they are affected by the weather conditions. Energy storage can help integrate them into power grid by reducing their stochasticity and improving their controllability. For the aspect of electric energy supply, energy storage can be applied to time-shift electric energy and explore margins of existing electric supply capacity. Redundant electricity at off-peak hours is bought at low price and to charge the energy storage plant, so that it can be sold at peak hours with higher price. Electric energy time-shifting can help explore margins of exiting electric supply capacity, defer the need to add new investment in generation capacity. Ancillary services include load following, area regulation, voltage support, and so on. Ideally, power generation should follow power load. Since energy storage usually responds quicker than power generation facilities, it can help achieve load following more effectively and efficiently. Area regulation aids to reconcile momentary differences between power supply and power demand within the control area (Hirst and Kirby, 2000). Energy storage is able to offset reactive effect and correct power factor, so as to maintain necessary voltage levels with the required stability (Hirst and Kirby, 1997). For the aspect of electric power transmission, energy storage can be applied to relief congestion, defer upgrade of transmission and distribution facilities, supply on-site power for utility substations, and so forth. By installing energy storage systems at locations where power flows downstream from congested portion, they can help reduce congestion-related costs and charges. Of course, this could lead to the deferral of upgrading transmission and distribution facilities. Energy storage devices, such as lead-acid batteries, have been extensively used to provide power to the equipments installed in utility substations when grid is not energized. For the aspect of end consumer applications, energy storage can be used to manage time-of-use energy cost, guarantee electric service reliability, improve power quality, and so on. Customers can attempt to reduce their overall energy costs by charging energy storage during off-peak hours when electric energy price is low, and then discharge it during peak hours to avoid high electricity price. In events of sudden power outage, energy storage can provide uninterrupted power, so as to avoid disorders. Moreover, energy storage is able to improve power quality by suppressing harmonics, correcting current frequency, supporting magnitude of voltage and increasing power factor.

In summary, energy storage is able to enhance the efficiency, cleanness, reliability and stability of whole energy system. Adding energy storage to existing energy system should follow the engineering philosophy, the core of which is system integration and optimization. The principles of integrated system design can be summarized into the following six points:

Debate, define, revise and pursue the purpose/objective: The system exists to deliver capability, the end justifies the means. The statement of a requirement must define how it is to be tested. Requirements reflect the constraints of technology & budgets.

Think holistic: The whole is more than the sum of the parts–and each part is more than a fraction of the whole.

Be creative: See the wood before the trees.

Follow a disciplined procedure: Divide and conquer, combine and rule.

Take account of the people: To err is human; Ergonomics; Ethics & Trust.

Manage the project and the relationships: All for one, one for all.

4. CORRELATION BETWEEN ENERGY AND INFORMATION

The integration of energy and information is crucial (Chan, 2013). It is a pervasive feature of the nature and society that exists almost everywhere. As shown in Figure 4, the circulatory system and the nervous system harmoniously coexist in human bodies, so as to support our normal function and activities. Circulatory system transmits energy flow that carried by blood, while nervous system transmits information

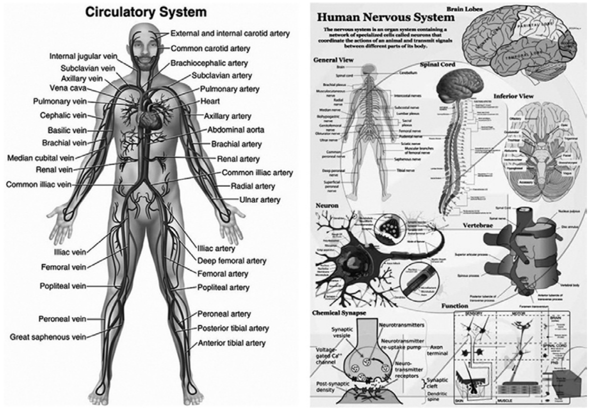

Fig. 4 Coexist of circulatory system and nervous system in human body

Fig. 5 Integration of currency flow and new in financial industry

flow. Figure 5 shows that in financial industry, the currency flow is always accompanied by the financial news flow. Currency is the token of wealth, which is represented by energy and resources. No one can ignore news and information when coping with their wealth.

Observing from Figure 6 to Figure 10, it can be summarized about the correlation between energy and

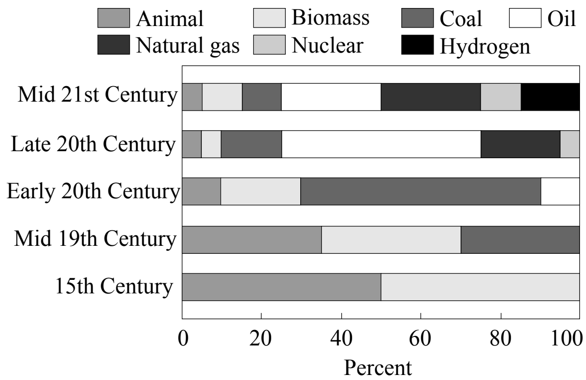

Fig. 6 History of energy source since 15th century
Source: http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/evolenergy.html

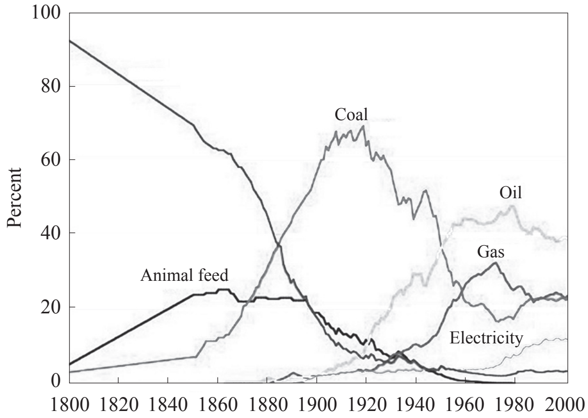

Fig. 7 History of energy source in percentage
Source: http://www.eoearth.org/article/Energy_transitions_past_and_future

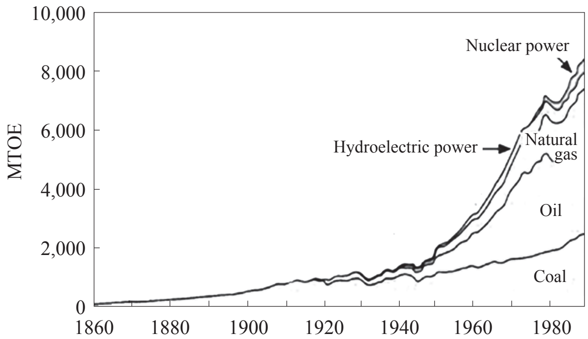

Fig. 8 History of energy use
Source: Agency of natural resources and energy, a brief history of energy strategies and outlook for the future

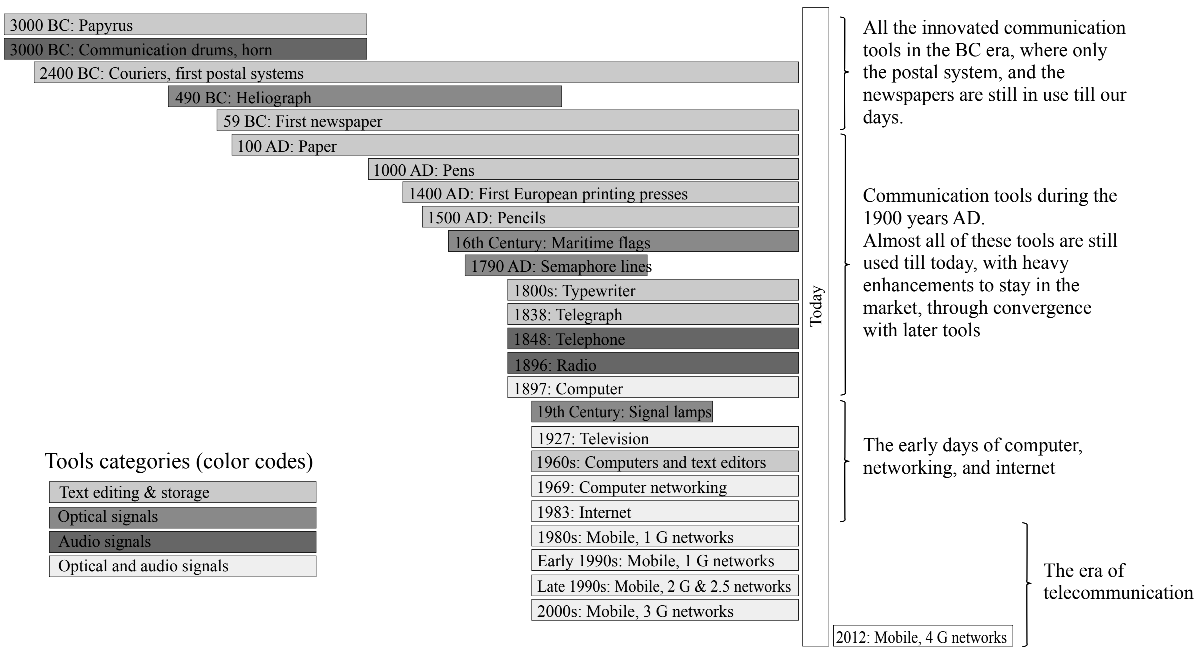

Fig. 9 History of communication tools
Sources: 1. Wikipedia; History of telecommunication; 2. Book; Mobile marketing, by Alex Michael & Ben Sater

information as follows: During the first industrial revolution (19th century), the main energy source was coal, while the main information technology was telegraph. During the second industrial revolution (20th century), the main energy sources were oil & gas, while the main information media were radio and television. During the current third industrial revolution (21st century), the main energy sources should be towards renewable energy, while the main information technologies are internet, cloud computing and big data systems. Therefore the evolutions of energy and information have always been hand in hand, hence the correlation between energy and information is essential.

Today, what is more, the most essential feature of the emerging smart grid lies in the integration of energy flow and information flow as illustrated in Figure 11. Smart grid allows the bi-directional energy flow, and this is a key enabler for distributed renewable energy utilization, smart charging (Faruqui et al., 2011) or even vehicle-to-grid technology (Guille and Gross, 2009).

It has been stated that adding energy storage is the essential solution to the challenges faced in future new energy system. More importantly, to make energy storage systems function effectively, the key issue is to integrate information into energy. This concerns a series of questions: (1) Where to deploy energy

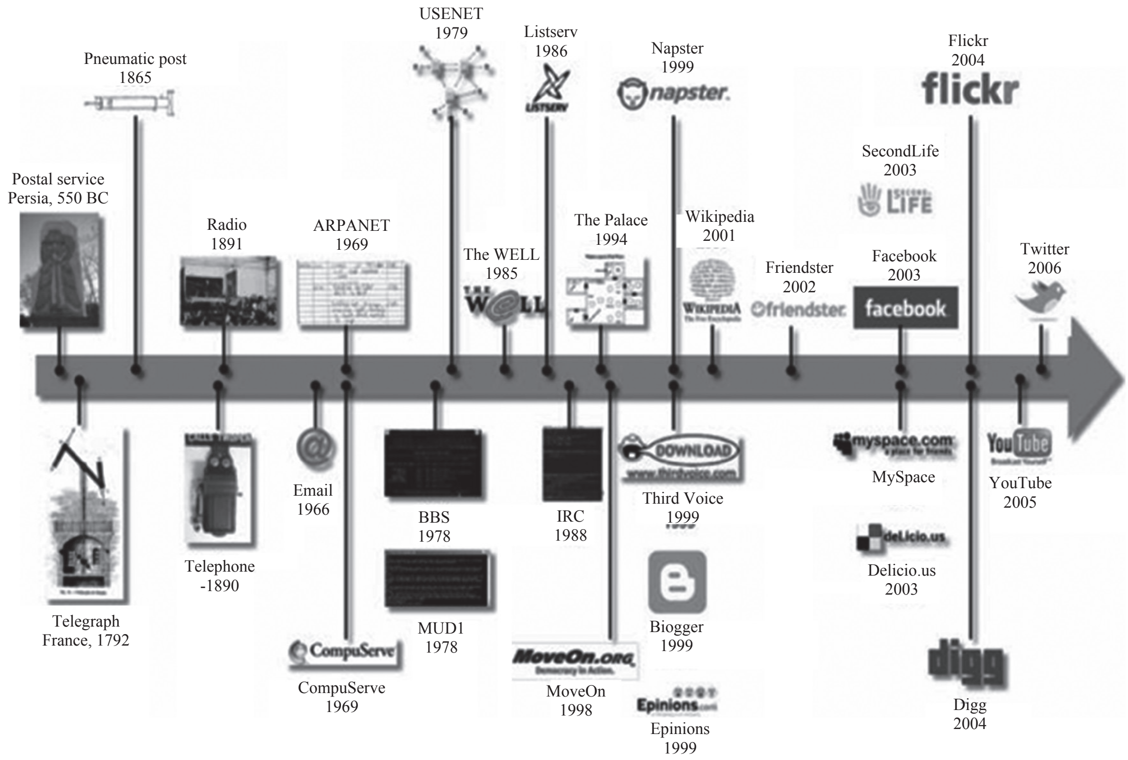

Fig. 10 History of communication media

Source: http://www.crexendoseo.com/blog/post/2728568

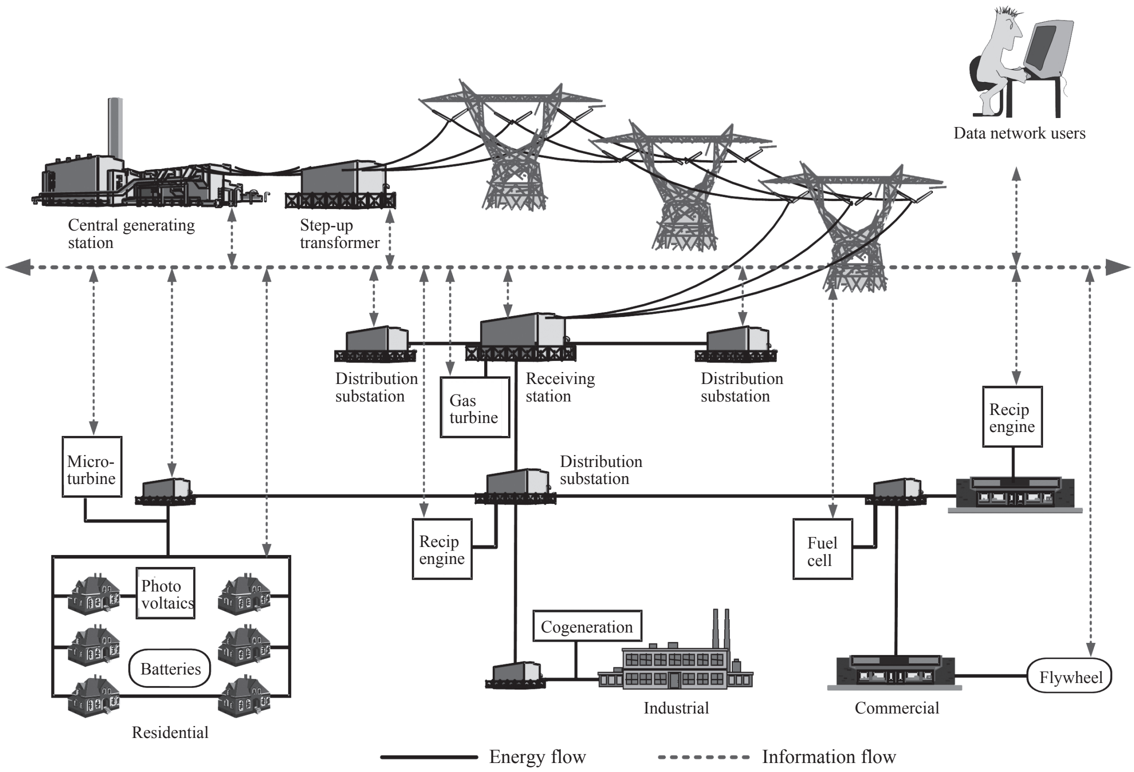

Fig. 11 Integration of energy flow and information flow in smart grid

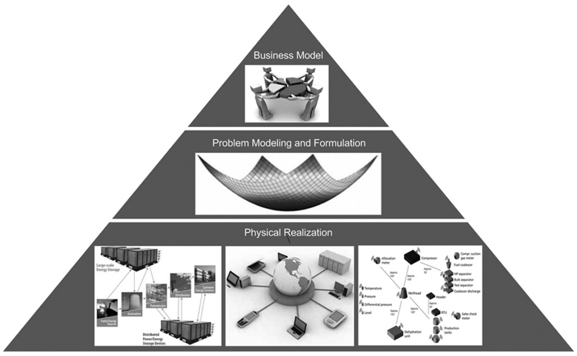

Fig. 12 Three-layer consideration for adding energy storage

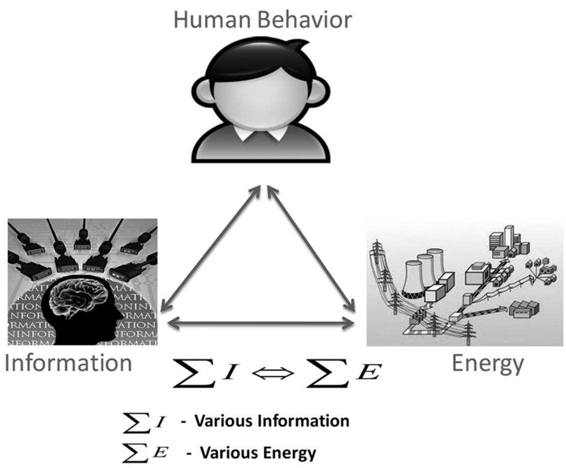

Fig. 13 Inter relationship among human behavior, energy and information

storage devices?; (2) How to design the energy storage network?; (3) What kind of energy storage is the most suitable for what kind of occasions?; (4) What scale of energy storage is needed for any specific applications?; (5) When to charge the energy storage devices?; (6) How much energy should be stored at any specific time slots?; (7) When to release the energy stored in the energy storage devices?; (8) At what speed the stored energy should be released?; (9) How to make profit?; (10) Who invest? Who benefit? As shown in Figure 12, the problem could be considered from three levels. The top level question is what the basic business model should be. This is a question involve many issues, such as the people's lifestyles, the condition of the existing power grid and existing energy suppliers, the government policy, and so on. The middle level question is how to model and formulate the problem. What are the control objects? What are the key variables? What are the constraints? What are the control strategies? The bottom level question is the physical realization. How to construct the energy storage network? How to layout the sensor and communication network? How to configure the computing resources? Figure 13 shows the inter relationship among human behavior, energy and information.

There may be a deeper problem behind all this: whether there is any physically inherent correlation between Information and Energy? Information, in its most restricted technical sense, is a sequence of symbols that can be interpreted as a message. In Physics, information also has a well-defined meaning.

Early work demonstrated by the Maxwell's demon thought experiment in 1867 (Radhakrishnamurty, 2010). In this experiment, a direct relationship between information and another physical property, entropy, is demonstrated. A consequence is that it is impossible to destroy information without increasing the entropy of a system. In practical terms this often means generating heat. Another, more philosophical outcome is that information could be thought of as interchangeable with energy. Thus, in the study of logic gates, the theoretical lower bound of thermal energy released by an AND gate is higher than for the NOT gate (because information is destroyed in an AND gate and simply converted in a NOT gate). Physical information is of particular importance in the theory of quantum computers.

In 2003 J. D. Bekenstein claimed that a growing trend in physics was to define the physical world as being made of information itself (Bekenstein, 2003). Examples of this include the phenomenon of quantum entanglement where particles can interact without reference to their separation or the speed of light. Information itself cannot travel faster than light even if the information is transmitted indirectly. This could lead to the fact that all attempts at physically observing a particle with an "entangled" relationship to another are slowed down, even though the particles are not connected in any other way other than by the information they carry.

In 2010, Maxwell's demon was experimentally verified by several Japanese scholars. It demonstrates that the information on the motion of a nanoscale polystyrene bead in a bath of buffer solution can indeed be converted to its potential energy (Toyabe et al., 2010). We should take this into account when we formulate the model of the correlation between Information and Energy.

The transformation of energy and information should be correlated and coordinated. Both Energy and Information should be sustainable. Information and communication technology (ICT) will no doubt contribute to the sustainable energy, nevertheless the sustainability in ICT is should also be addressed, such as energy efficiency in ICT and environment impact of ICT. The authors propose that the correlation between Information and Energy can be expressed by (1), where ΣI are various Information, ΣE are various Energy.

$$\Sigma I \Leftrightarrow \Sigma E \quad (1)$$

The above expression (1) provides general guidelines for integrating Energy and Information. Further expression can be derived for different applications.

5. CONCLUSION

The only way out for keeping sustainable development of human beings lies in changing the energy consumption modes and building new structure of energy system. The characters of new structure of energy include the diversity of both energy sources and energy flows. The diversity of energy source aids to improve the sustainability of energy consumption, and the diversity of energy flow aims at maximizing the overall efficiency of energy utilization. Adding energy storage is the essential solution to the challenges arising from the uncertainties of both power supply and power demand in the future's energy system. The roles of energy storage in emerging new energy structure generally lies in five aspects, including renewable energy integration, electric energy supply, ancillary services, electric power transmission, and end customer applications. In order to make energy storage systems function effectively, the key issue is to integrate information into energy. This uttermost importance of the correlation between energy and information has to be paid full attention in every aspect of our efforts towards developing sustainable energy system. The correlation between Energy and Information has been proposed as $\Sigma I \Leftrightarrow \Sigma E$ which laid down the general guidelines for the integration of Energy and Information.

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