Energy Internet – Towards Smart Grid 2.0

Junwei Cao and Mingbo Yang

Research Institute of Information Technology

Tsinghua National Laboratory for Information Science and Technology

Tsinghua University, Beijing 100084, P. R. China

Email: jcao@tsinghua.edu.cn

Abstract – **Price rising of energy and the limitation of fossil fuel makes it an inevitable tendency to introduce distributed energy such as renewable energy to the existing supply system in the future. Different players, such as power generation, transmission, and distribution, along with the value chain must now cooperate and interact with each other by shared interfaces or eventually a customized network for secure and reliable delivery of energy. While smart grids are focusing on the informationization and intellectualization of the existing power grid, the new concept of an energy internet is proposed as an internet-style solution for energy issues by integrating information and power flows bi-directionally, which can be considered as the version 2.0 of smart grids. Some key features of an energy internet compared with conventional energy grid such as openness and peer-to-peer are introduced. Architecture of an energy internet is proposed in details, including energy storage, switches and routers. The definition of an energy internet call for a much greater degree of interactive flexibility for efficient energy management than the present system is designed to handle.**

Keywords - **energy internet; smart grid; energy router; distributed generation**

I INTRODUCTION

In the 20th century, the conventional electric grids had become very large, mature and highly interconnected energy infrastructure. Thousands of central generation power stations deliver power to major load by utilizing high capacity power transmission lines. This way of power delivery was a result of benefit driving as coal-, gas- and oil-fired power station could be more cost-effective as running in large scale. Nonetheless, it's widely recognized that fossil fuels are going to be gone and they are going to become more and more expensive to use, besides, it's a fact that the climate is changing and the fossil fuel emissions are contributing greatly to the deterioration of the situation. So renewable energy in form of distributed energy needs to be put on the agenda to mitigate the economic and environmental pressure we are facing. Growing concerns over environmental damage from fossil-fired power stations has led to a desire to utilize renewable energy instead of the former as well. So, both the government and power operators are trying to find ways to get out of the dilemma.

Improvement of technologies in two fields provides the enlightenment to deal with the issues, the development of renewable energy and the advances of information and communication technologies (ICT). With the former, we can have the assurance of sustainable power source provided in way of steady stream. This doesn't mean we are going to shift electricity generation off of the fossil fuels and turn to renewable energy now, the exiting energy infrastructure is indispensable now and it will play a leading role quite a time. What we are trying to do is to fuse the use of both and make a gradual shifting from the former to the new application to help us getting rid of the dangerous position due to our complete reliance upon one single finite input.

Taking advantage of advanced ICT to resolve limitations of the electrical grid becomes apparent and unavoidable. ICT provides a way leading to for smart grid by utilizing intelligent control of the electrical grid and making it possible for distributed energy to access the backbone grid. There are many smart grid definitions, some functional, some technological, and some benefits-oriented. A common element to most definitions is the application of information processing and communications to the power grid and making data flow and information management central to the smart grid. As a modernized electrical grid, it uses ICT to gather and act on information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity [1].

The smart grid was considered within the context of optimal control, ecology, human cognition, glassy dynamics, information theory, microphysics of clouds, and many others [2]. Most of those could be concluded as one or other aspect of complex systems which is an extremely difficult optimization problem without any analytical solution. Multi-agent (or intelligent agents) has been discussed as one approach to fix the issue [3]. With intelligent decision system and cooperation mechanisms between agents, the search for solutions instead of established solutions is explicitly formulated in this complex system. Although this seems available to be achieved, there are still many technical issues such as information collection (e.g smart metering with unique addresses and communication capability), reliable and secure transmission of information, decision making of multi-agents, fusion of information and physical devices etc. Each of them could be figured out respectively while

the task becomes huge when all of them are mixed together.

Ideal smart grid is expected to be a transmission network which is able to efficiently transmit and route energy produced from both concentrated and distributed generations to or between end users. So the smart grid is expected to be a type of energy internet by which the energy could be packed and delivered to different addresses across energy switches, routers and gateways. This energy internet decides the best pathway by considering information such as load states or price information or even supplying status in a local area to achieve better user experience with loss minimization and benefit maximization. Energy internet could be one solution for such a complex system for its power of administration of power networks in an open and peer-to-peer way. It includes but not limited to an internet style smart grid which allows a real time balance between the local generation and storage capability, and allows high level of consumer awareness and involvement in form of cooperation and interaction as well. Energy internet is considered as a smart grid 2.0 from a perspective of information technology.

II. TOWARDS AN INFORMATION CENTRIC INFRASTRUCTURE

Fusion of information and energy is an effective way of real-time information acquisition and control strategy implementation. By way of integrated computing and network distribution being blended to infrastructure, information-infrastructure fusion has gained extensive attention by many countries, and lots of research production emerged.

A) Cyberinfrastructure of US NSF

The term "cyberinfrastructure" was used by NSF in 2003 in response to the question: how can NSF remove existing barriers to the rapid evolution of high performance computing, making it truly usable by all the nation's scientists, engineers, scholars, and citizens. Cyberinfrastructure consists of computing systems, data storage systems, advanced instruments and data repositories etc., all linked together by software and high performance networks to improve research productivity and enable breakthroughs in other fields [4].

The four layer structure of cyberinfrastructure which is provided by the US NSF is shown as Fig 1. Process layer provides basic functions for the system including basic computing, data storage, and communication. The transport layer is made up of networking, operating system, and middleware, and provides the service layer with interfaces and drives. The services layer utilizes resources mentioned above for high performance computing, knowledge management and interfaces visualization services. Application layer is based on services layer and it enables the applications shown in the chart. The challenge of cyber-infrastructure is to integrate relevant and often disparate services to provide a useful,

usable, and enabling framework for research and discovery, which is characterized by broad access and "end-to-end" coordination.
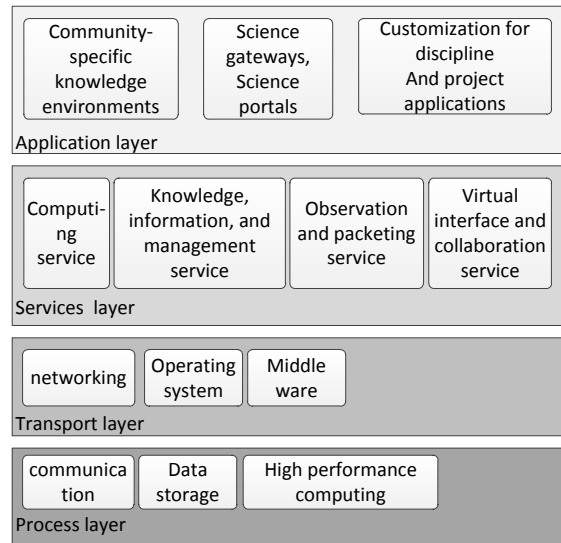

Fig. 1 Layer structure of NSF's cyberinfrastructure

B) Cyber-physical systems (CPS)

Cyber-physical system is a multidimensional complex system which deeply synthesizing computation, network and physics environment to achieve the real-time perceiving, dynamically control and information services with reliability, efficiency and real-time collaboration. Unlike more traditional embedded systems, a full-fledged CPS is typically designed as a network of interacting elements with physical input and output instead of as standalone devices [5].

Cyber-physical system which adds computing, communication, accurate control, remote cooperation and self-government function to infrastructure emphasizes the close integration and coordination of computing resources and physical resources. In real world application, CPS can fuse the informationalized network into the existing infrastructure without destroying or even disturbing the physical facilities and computing logic. At the same time, any software or physical structure belongs to the system should be able to dynamically join into the system without being suspended or shutdown, so as to guarantee the system requirements and quality of service. So CPS relates to wide range of areas such as smart traffic, telemedicine, smart grids and so on.

C) Berkeley structure

An information-centric energy infrastructure is an information overlay on the energy distribution system in its various physical manifestations, e.g., machine rooms, buildings, neighborhoods, generation islands and regional grids [6]. Fig. 2 presents a schematic view of such an overlay network.

By using well defined interfaces intelligent power switch (IPS), suppliers, loads and energy storages can interact with each other in the subnet. Total demand and supply of the constituents in this subnet can be represented by a schedule which has the function of forecasting and adapting of the trading status. This

structure also provides the communication exchange that accompanies the on-going energy transactions between supplies and loads
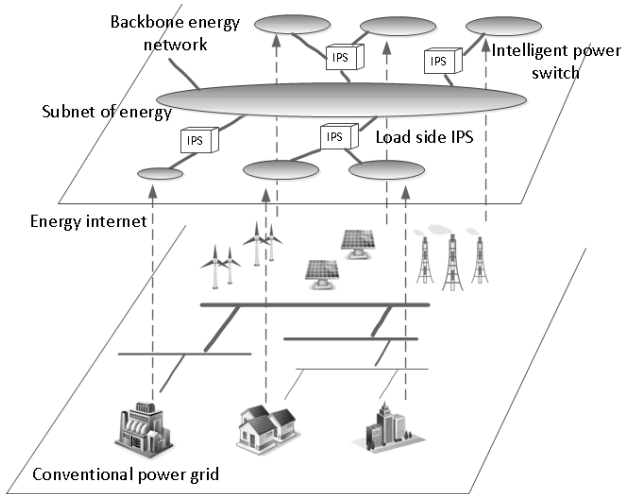

Fig. 2 Information-centric energy infrastructure

Such a structure can provide a distributed and integrated energy management system that could also buffer energy and moderate infrastructure provisioning in the process of information-infrastructure fusion.

III. KEY FEATURES OF ENERGY INTERNET

Energy internet provides innovative concept and envision for enhancing the capability of electrical grid in form of internet style power generation, power distribution, energy storage, grid monitoring and communication. When the current energy infrastructure is fused in an open and peer-to-peer internet-style way, the whole energy system will enter the ideal state of balance, which contains the power output balance for energy utilities and the consumption balance for users.

The most wanted feature of energy internet is that energy units can be packed and transferred when and where required safely. This requires monitoring and intelligent management of users' power consumption. Information acquisition could be performed on all levels of energy systems, from locally individual devices up to national and international levels. It helps to decide in which time the electricity would be cheaper and also be able to mitigate the burden of power grid.

The technical support system of energy internet could be divided into five parts: system plan, energy sources, information and communication, administration and scheduling, and security defense [7]. Several key features are as follows:

A) Internet based energy solutions

Networked energy management must be one foremost characteristic of the features of next generation of power grid. Thus ICT would play an essential role in enabling the full functionality of an intelligent distribution power grid. The overall control requires internet based sensors and actuators to monitor the state of the consumer side grid and the generation side by way of an internet-style approach.

The energy internet links the distributed generation, energy storage and loads to build an energy grid with information flows and power flows simultaneously and bi-directionally. The introduction of internet makes it possible to achieve a bottom-up approach to deal with the technical difficulty and policy dilemma of defining and scheduling the global health of a power system which has been met in a top-down mode. While, the conventional grid focused mainly on how to access these distributed generation instead of networking of them. This makes it hard to thoroughly change the operating mode of electrical grid. Although there are communication facilities equipped with or along the grid, they makes nothing but a star like organizing structure instead of the network structure while only the latter could deal with power balancing issues penetratively and gradually.

B) Information based anticipatory control.

Anticipatory control behaves as indispensable feature supporting the advancement and availability of energy internet. Anticipatory control consists of two parts, anticipation of future states and intelligent decision-making based on the anticipation.

The combination of network techniques and anticipatory control give us a promising solution of running state prediction of the power grid. The highlight of this function lay mainly on its farther future vision compared to conventional alternatives which utilize current-state information to behave and affect change. From the angle of control theory, anticipatory control poses feed forward control on the energy distribution strategy. It could have great effectiveness on improving the power quality and security issues because feed forward control of power distribution can bring us with lower maintenance costs, higher reliability and a substantial reduction in hysteresis.

C) Interoperability based feedback control

Interoperability based feedback control makes the energy internet an self -organization mechanism. Free and dynamic access of the energy internet is common attributes of each part of the network. Huge number of distributed energy systems and micro grids compose the energy internet, and they can smoothly interact with each other via standard protocols and appropriative way of communication. The mounting or unmounting of energy generations or energy routers brings slight affect to the normal operation of the local grid. With standard configuration information, devices linked in the grid can access other device's state information and send commands to start an energy flow on demand of local energy requirements.

Interoperability provides devices in an energy internet the ability to recognize each other. Envisioned approach is internet-style communication protocol to deliver message and power hierarchically between different levels of terminals, for example, between the end consumers, between the local micro grids, or between different layers. With layered mechanism, the efficiency

and security ability of communication in an energy internet could be enhanced radically.

D) Networked distributed generation

The advantages of large scale energy production are mainly behaved as its efficiency, with distributed generation, it would be offset against the necessity to operate isolated units close to the consumer, and furthermore we need to operate a district system to distribute power. Connection of distributed generation in this way poses many technical, commercial and safety issues and all of which must be handled for the access to larger scale of energy grid made up of micro-grids.

Besides, the introduction of distributed renewable energy requires the adjusting of fluctuating consumption according to the fluctuating supply and the variable energy prices. With the application of distributed generation, new management models and business models with variable pricing policy must come into play.

E) Energy storage

Energy storage provides energy internet with absolutely new feature compared to the current power grid. For one thing, energy storage can improve the quality of electricity and help maintain the stable operation of the system. For another thing, it has the function of energy deployment which could help peaking power and output power if needed. In conventional form of power delivery, utilities rarely use any type of devices to store energy and this constrains the grid operators to match supply and demand at all times to prevent blackouts. Besides, without energy storage, there is no energy buffer to output power locally in the grid by which the grids can fulfill the function of self-heal immediately during emergent power cut. Several energy storage technologies are available now: advanced batteries, super capacitors, flywheels and super conduction devices etc. So, if energy could be widely stored on the grid in a distributed fashion and be released cheaply and efficiently when required, it would enhance the robustness of the energy grid greatly.

IV ENERGY ROUTERS

In the future electrical grid, energy switches and routers will be a fundamental and indispensible equipment to support energy management just like a router behaves in the internet. To achieve the function of information linking, energy distribution and system state monitoring, the architecture of the energy router should basically compose three modules such as power electronics devices, communications unit and intelligence center. General architecture and its relationship with energy flows are shown in Fig. 3.

Solid lines are used for indicating energy, dotted lines are for communication. In a real world application, energy storage should be linked to energy routers as well to achieve energy interaction between the same levels of consumers.
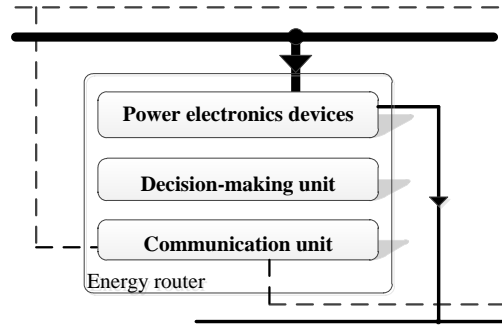
A) Distribution of energy

Fig. 3 General architecture of an energy router

An energy router could be the bridge between the energy sources and users. So one of its key functions is fusing of energy comes from different resources. Besides, energy routers should guarantee the power quality otherwise the fusing of energy would make no sense. Furthermore, the function of energy balancing is obligatory. Take electricity power as an example. If huge amount of power is produced which beyond the need of the local existing consumers, the energy router could send the surplus power to the grid for neighborhood power usage. On the contrary, the router can introduce power for local grid when local energy production is in state of insufficient. Special services are required to provide quantitative price of energy according to exterior reasons such as weather, amount of demand or supply etc.

B) Intelligent power management

The energy router is required to monitor the change of supply and load in time to maintain the proper amount and direction of energy flow in the grid. In fact, the utilities supply or the user demands varies all the time, the energy routers have to track the state changes to adapt the energy distribution dynamically. Furthermore, the router is able of provide anticipatory control of energy stream flow according to the historical usage patterns such as amount of energy consuming in dedicated length of time. This could help to mitigate the burden of power grid and reduce the loss caused by blindness flows of energy streams.

C) Network configuration and management

Network configuration and management is the base of energy internet as well. The energy router provides the platform for implementation of network management. From the angle of networked functionality, configuration and management should comprise access and recognition function, remote deployment of management policy, exception handling and recovery, configuration and management of logs. Any type of energy supplier such as renewable energy resources, distributed energy storage devices or the loads can access the local network after configuration, and then an 'IP' is assigned for identifying and remembering of the source. Several sources construct a microgrid and each source in the same microgrid communicates with the energy router for all the subnet services.

The energy router connects not only the suppliers but also the consumers to maintain power balancing which

has been mentioned before. Furthermore, the energy router connects other routers in the same grid. So each router could be either the supplier or the consumer of the other router. The role is defined by the flowing direction of the energy stream. The one who outputs power must be the supplier of the one who receives power, and vice versa. Network configuration and management could be really complicated because its responsibility is to give the energy grid the property of network which has been recognized as one type of complex systems. That is the reason why internet mechanism is introduced to address energy issues.

Distributed energy sources in form of wind power, solar power or battery storage may not be able to support the power requirement of small local area for long time, and besides, in some special circumstances, the amount of power consuming of one area may fluctuate to a high level which is beyond the capacity of the local distributed generation. At this time, energy router could show its superiority by connecting the neighborhood distributed generation to compose a local area network for balancing and co-ordination of power supply and power demand. Under this situation, surplus energy could be used efficiently.

V. ARCHITECTURE OF ENERGY INTERNET

Energy internet must be the innovation of energy infrastructure with openness and peer-to-peer features, borrowed from internet technology. It is also essential to achieve the fusion of energy and information flows. Thus, to design and explore the structure of energy internet from the perspective of CPS is beneficial to resolve the issues of deep fusion of energy and information flows [8~10].

Just relying on the existing demand-response measuring and dispatching system of power grid, we may not be able to change the current power grid into the infrastructure of energy internet. While, in response to this issue, the development of internet have given us good examples. In the past decades, intelligent organization principle is created by internet accompanies with its development. By deploying intelligence features such as intelligent edge switches and defining interfaces which covers diversified underlying technology, the internet has achieved great success. Intelligent edge switches focuses mainly on the control of user access, so although its ability of exchanging capacity and packet forwarding rate is lower than backbone intelligent switches, it enables the accessing right of devices, this is a tremendous success.

According to the development of information internet, any device located in energy internet could be the router of energy which plays the role of transmitter and receiver of energy. As for energy routers, hierarchy mechanism of router should be designed to fulfill different levels of energy routing as the way backbone switch and intelligent edge switch work in the internet. Intelligent terminals then adjust its operation according to local power supply

situation of infrastructure.

Now, infrastructure has been widely deployed and huge cost has been input, it's not practical to replace the existing infrastructure radically for new plans. Also, we could utilize the development mode of internet. Long-tern coexistence of infrastructure with service replaced step by step. Fig. 4 shows the current infrastructure based structure of energy internet. This architecture of energy transferring is similar to the mechanism of internet. There are five layers in this architecture which could achieve the bottom-up approach of management mechanism. The foremost feature of this structure is the applying of energy routers. The networking of hierarchical energy routers and the routing of energy comprise the fundamental and special working principle. The introduction of energy storage devices breaks the synchronization between power generations and loads. This control process is performed as network buffer in internet which has decoupled the transmitter and the receiver. All of this needs energy routers to conduct and coordinate.

Communication protocols and energy delivering are integrated for distributed control and continuous response of price signals and surplus power. The peak and worst case based power supply strategy would be changed and more concerning will be focused on average requirements. In current power grid, peak power prices are being averaged out and passed on to all consumers equally, this situation will not happen in energy internet. This is similar to the statistical multiplexing of packet network in internet. Then the system takes the reserved space in electrical grid capacity as a primary input parameter to control the electricity generation, energy storage and the loads of the local grid.
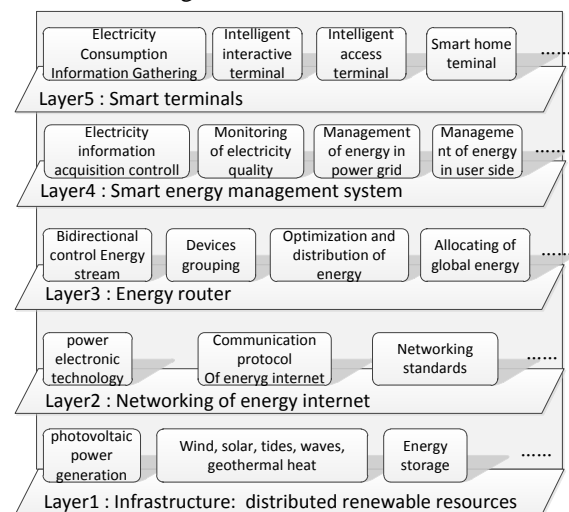

Fig. 4 System architecture of energy internet

Energy internet can be concluded as an internet based WAN for information and energy fusion. It takes the electrical grid as backbone network and the microgrid or distributed energy sources as local-area network. With the integration of information and energy, bidirectional flow and dynamically balancing of energy is achieved. With

new generation of information-centric and internet modeled architecture and integration of information and energy, deep fusion of information and energy flow is achieved. Energy sources can cooperate and interact with other sources or even the energy consumers. It makes open deployment of energy infrastructure and efficient consuming of energy possible.

VI. CONCLUSION

Development of electrical grid is introduced for addressing energy internet. The trend of information and infrastructure integration is discussed with features like openness and peer-to-peer. Technology architecture of energy internet is proposed in details. Foremost features of energy internet which is beyond the scope of general smart grid are analyzed and five layer architecture of energy internet is introduced. Building the energy internet will be the answer to a number of the energy challenges related to the implementation of the infrastructure for the full deployment of the renewable energy production, while the advancements in power electronics, energy storage, communications, control, data centers and internet technology are the enables that will make the implementation of the concept possible.

While current electrical grid is evolving to a smart grid, open energy is becoming a universal trend. An energy internet is representative of such trend, which could be considered as an era of smart grid 2.0. Just as in an information internet, Web 2.0 enables information sharing in a peer-to-peer way, future energy internet will become an open infrastructure where future energy producing, consuming, and sharing will become as convenient as information sharing today.

REFERENCE

[1] U.S. Department of Energy, "Smart Grid System Report", 2009.

[2] Paul Bourgine, David Chavalarias, Edith Perrier, Frederic Amblard, Francois Arlabosse, Pierre Auger, Jean-Bernard Baillon, Olivier Barreteau et al. "French Roadmap for Complex Systems 2008–2009", 2009.

[3] L. H. Tsoukalas, R. Gao. From Smart Grids to an Energy Internet -- Assumptions, Architectures and Requirements. Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, 94-98, April 2008.

[4] J. Cao (Eds.). Cyberinfrastructure Technologies and Applications, Nova Science Publishing, 2012.

[5] Edward Lee. Cyber Physical Systems: Design Challenges. University of California, Berkeley Technical Report No. UCB/EECS-2008-8.

[6] Randy H. Katz, David E. Culler, Seth Sanders, Sara Alspaugh, Yanpei Chen. An information-centric energy infrastructure: The Berkeley view. Sustainable Computing: Informatics and Systems. (2011) 7–22:8-24.

[7] Yabing Zha, Tao Zhang, Shuren Tan, et. al. Understanding and Thinking of the Energy Internet. Defense Technology, 33(5), 2012.

[8] Jianhua Zhang, Wenye Wang, Bhattacharya, S. Architecture of solid state transformer-based energy router and models of energy traffic. 2012 IEEE PES Innovative Smart Grid Technologies, 2012: 1-8.

[9] Patrick Favre-Perrod. A vision of future energy networks. Power Engineering Society Inaugural Conference and Exposition in Africa, 2005: 13-17.

[10] Martin Geidl, Gaudenz Koeppel, et al. Energy Hubs for the Futures. IEEE Power & Energy Magazine, 2007(1): 24-30.