Toward Implementing Power Packet Networks

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***Abstract*—"Power Packets" are one of useful ideas of power distribution for a highly-efficient and comfortable society with a low environmental impact and energy efficient systems. It has yet to be shown that it is feasible to generate physical electric power packets and control them with computers. This study aims to organize the past achievements from the point of view of our studies. This study offers a map for the studies of Power Packets and suggests a direction for new studies in this area.**

Introduction

A highly-efficient and comfortable society with a low environmental impact needs energy efficient systems, and energy efficient systems need flexible systems for power distribution.

For maximum application of the Internet technology to electric power distribution systems, we have the following principles because they are the key technologies of the Internet;

- A finite amount of energy and information has to be packed together into an individually identified packet (i.e. Power Packet).
- Every transfer of a power packet has to be exactly controlled by computers.

This implies that electric circuits should be localized well in order that unexpected electric faults and disturbances are limited to a small part of the system.

Furthermore, our Internet-like power packet networks should be equipped with the following features;

- Simple and robust LAN technology (such as Ethernet)
- Multihop, store-and-forward and bi-directional transfer
- Layered and distributed architecture
- Best effort, end-to-end principle and narrow waist model

While most parts of the Internet are currently running by Ethernet, power packet networks need a fundamental technology developed and standardized in future, which will replaces AC power flow by phase control. An in-home power network has a suitable size for a power LAN, therefore, we are focusing on an in-home power network and its appliances.

Currently we are proposing a simple LC circuit to transfer electric energy between capacitors. This method is the simplest way and enables us to count "electricity" easily. Toyoda's circuit configurations [1] [2] and Fujii's[3] should be considered as other ideas.

In this paper, we looked back upon past studies and made our position clear.

The Pioneer: Saito and Toyoda

In 1993, Saitoh and Toyoda[4] proposed "Concept of Open Electric Energy Network (OEEN)" and "Packet Electric Power Transportation." A packet was defined as something that had information of its sender and receiver and that could be temporarily stored in power storage devices in the network in case of imbalance between supply and demand. They also brought the concept of data driven power flow, its autonomy and distributed control into electric power distribution systems.

Saitoh, Miyamori, Shimada and Toyoda[2] also described in English more detailed discussion about the power network they proposed. They showed the concept of electric energy packets which were electric energy provided with tags including flow control data and price data, however, the paper also pointed out that electric energy packets could not be "discretized" in the form of packets because power flow was a continuous quantity and that integration of information and energy was also actually impossible. The paper also introduced the "electric energy router," and presented the basic circuitry and results of computer simulation for a small-size experimental router.

They also proposed concrete circuit configurations of power routers. The combination of buck converter and boost converter was proposed in their report[1] in 1995 and buck-boost converter was proposed[2] in 1997.

Internet and Power Network

The 2000s was the decade of the Internet, the network of autonomous networks, which has been a greatly successful innovation. It is also the decade of solar and wind power generation.

In 2005, Matsumoto and Yanabu[5] discussed networks of "clusters" connected each other by "electric power routers" they proposed. They mentioned the necessity of "packets" and "best effort" concept, and also pointed out that the physical integration of electric power transmission lines and digital data communication lines via the same metallic cables must be studied. They listed clearly the concepts of their new electric power network. It included the essential transitions of technological paradigms, such as from hierarchical structure to network architecture, from uniformity to diversity, from guaranteed service quality to best effort and from AC to DC.

In 2008, Metcalfe[6], Matsuyama[7] and He at el.[8] proposed ENERNET, i-Energy and LoCal respectively.

Metcalfe[6] proposed a concept named "ENERNET." He stated clearly that the world needed cheap and clean energy by building the ENERNET as the world had obtained cheap and clean information by building the Internet. He also pointed out layered architecture as the winning principle of the Internet and discussed distributed architecture and topologies.

Matsuyama[7] also proposed integrating electric power and information networks, for example, which enabled us to recognize origin of electricity, which called "coloring". He showed

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and drove his plan for deployment of hierarchical structure from intelligent nano grids at home and regional area electric power networks to "mutual connections across a country like the Internet".

He et al.[8] pointed out the End-to-End principle and the Narrow Waist Model as network principles, which was the design principles of the Internet.

In 2010, Krylov, Ponomarev and Loskutov[9] claimed that SS7 service network was suitable for packet based power grid because of its administrative functions, while the Internet lacks such functions.

The researchers in this decade were conscious that the experience in the Internet would lead a revolution of electric power network. However, there was no technology to implement it at this time.

Residential Application

Studies for the realization of electric power packet networks started in the beginning of 2010s. They are divided into two groups; in-home network and regional network.

Firstly, we mention in-home network. In 2010, Takuno, Koyama and Hikihara[10] proposed and implemented a prototype system for power packet dispatching. In 2011, Sakai and Okabe[11] proposed another dispatching system and QoS routing on it.

While the dispatching systems mentioned above distinguished sources of electricity completely, the following researches were aimed at managing balance of shared power line. Kato et al.[12] started studies managing home appliances with intelligent power outlets. Stalling et al.[13] implemented "Smart Green Power Node (SGPN)" for automation of home power usage.

Secondly, we mention regional networks. In 2011, Inoue and Fujii[3] proposed distributed electricity markets using packet power transaction. They showed a conceptual circuit configuration and the result of circuit simulation. Their circuit looked to be based on buck-boost converter and the point of their idea was the shape of pulses given to switching devices.

Abe, Taoka and MacQuilkin[14] proposed "Digital Grid Router" and implemented it later. It connected among large asynchronous electric networks by using AC/DC/AC converters.

Theories for Control

Besides implementing electricity packets, studies for theories has been conducted.

In 2012, Gelenbe[15] proposed a model of Energy Packet Networks (EPN) and tried to solve several problems by using the G-network theory. Sugiyama[16] also constructed a scheme of pulsed power networks and showed algorythms to control them.

Concluding Remarks

We introduced the past studies chronologically and grouped them. This provided a clear explanation of the source of our idea. Our project will show the result of our design and implementation of power packet networks in future studies.

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