A Smart Metering Scheme for a Smart Grid System

Dai Weili and Lee W. K.

The University of Hong Kong
Department of Electrical and Electronic Engineering
Chow Yei Ching Building, Pokfulam Road, Hong Kong

ABSTRACT

The development of smart grid systems calls for new metering schemes in measuring consumption and power flow metrics between connected entities. The new meters which import the concept of renewable resource should also carry intelligence and communication compatibility for enhancement of new applications in demand side management. Our project explores network relationships of stakeholder parties in a smart grid system and their value channel behavior. A potentially successful smart metering scheme must carry a win-win-win scenario that satisfies all the partners involved. It is important to understand possible network partnership behavior. The scheme must resolve the potential contradictions and induce a balance of interests. Continuing our earlier study on the smart metering schemes, a derivative business model and the interface platform are further discussed by this paper.

Keywords: demand side management; smart grid management; smart metering scheme

1. INTRODUCTION

The recent development of information technology, advanced metering systems, energy management at the local level as well as household technologies open new opportunities for demand response [1]. Meanwhile, there is a growing need for a more active interaction between supply and demand side in power systems, and consumers are increasingly concerned about environmental and energy efficiency issues.

In normal grid system, a meter is a measurement tool between suppliers and consumers, while in the smart grid system a meter becomes an intelligent interface between multiple power-providers and end-users, which can fulfill many functions and management to the behaviors of the partnership.

A smart metering system is an upstream to downstream collaboration model for power networks. It matches quality home demand with quality power generation through collaborative trading efforts among the parties. A smart metering business model that proposed by Lee and Fung in earlier researches (*ICEE, Japan 2008*) [2] and an interface design suggested by Yang and Lee (*ICEE, China 2009*) [3] are the basis of the present study.

With the aggravation of the world's energy problem, many countries are considering use renewable resource as alternative energy to ease the current situation. So we import renewable suppliers as another partner (Auxiliary Supplier) in our business model which is a better approach to the situation in the future.

To manage the relationship and collaboration among the different partners, a middle agent has been proposed to act as the pivot of the whole smart metering scheme.

This paper discusses on the smart metering control system, schemes and incentives among the partners.

2. PARTNERS, PERSPECTIVES AND BENEFITS

2.1 The Value Development Model

Derived from the single-supplier-single-consumer value development model [2], our model shows a more complex structure with four different partners, which are main supply side, auxiliary supply side, mid-agent and demand side.

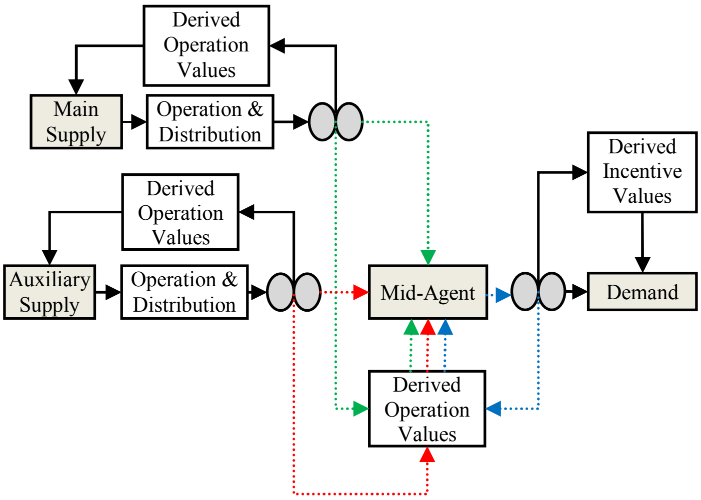

Fig.1 the Value Development Model

As shown in Figure.1, smart meters as interfaces are installed to build up connections between mid-agent and other 3 parties. With interface communication, data sharing and contracts, different parties cooperate with each other to obtain values. Main supplier and auxiliary supplier gain operation values and consumers gain incentive values from the interaction with the mid-agent. The mid-agent can also benefit from the 3 interaction cycles (shown by colored dotted lines). All parties are in a collaborative structure to maximize the total benefits.

2.2 The Value Channel

The scheme utilizes the value channel model, and invites all possible channel contributors to join the scheme so that value is enhanced throughout the channel (Figure 2).

As proposed by Lee and Fung [2], links are established in a value channel to enable partners offering incentives and accepting benefits between each relationship pair. The incentives and benefits can be tangible or intangible; and can be individualistic or societal. In the internal marketing loop of the suppliers and mid-agent, the nodes are its departments [4]. And in the evaluation loop of the consumer, the nodes are its appliances.

To realize the business model, partners should have contracts with each other. Also real time information is essential to this system. We need to build up an interface and control system to support the value creation between upstream supplier and downstream consumer as well as the value creation among the main supplier, auxiliary supplier and mid-agent.

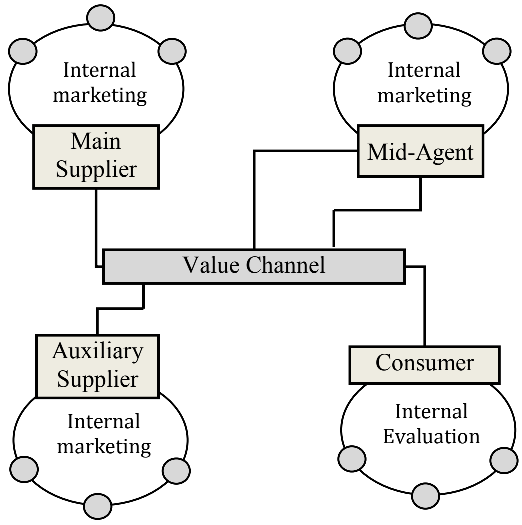

Fig.2 the Value Channel

Between the main supplier and consumer, electricity is delivered through a network system (e.g. a smart grid). Auxiliary supplier also delivers electricity to meet the consumers' demand. Suppliers will not have power supplier scheme directly with consumers but mid-agent has. At the same time mid-gent have contract with the suppliers and may provides different power-saving schemes to meet the request from suppliers or consumers.

Among the partners, a smart metering scheme is needed to support the value channel with the functional operation in real-time electricity monitoring, power flow control, safety assurance and scheme application.

3. SYSTEM ARCHITECTURE

3.1 Collaboration Structure

In our collaboration structure, main supplier, auxiliary supplier, and consumers don't have directly contract with each other but they all have a connection with the mid-agent which manages the smart metering system.

Considering the feasibility and efficiency for the renewable energy utility, the power generators are normally installed in an estate, which can be a skyscraper, an apartment building or a neighborhood unit, where the demand side can be easily reached. Most collaboration appears in the estate electricity grid, so we assign an estate manager for each estate electricity grid as the interface and power flow controller.

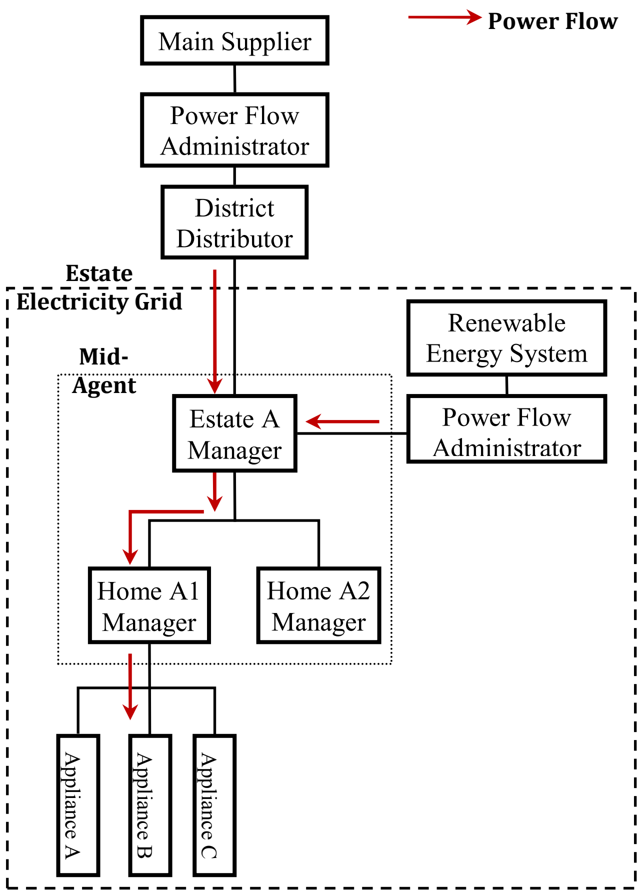

Fig.3 General Structure of Collaboration

As shown in Figure. 3, majority power flows from the main supplier through Power Flow Administrator, District Distributor into the Estate Electricity. Inside the gird, Renewable Energy System acts as the other power provider which provides the power generated by renewable resources such as wind and solar energy to the Estate Manager.

Estate Manager has the function of controlling the input power flow from different suppliers depending on the user consumption and the weather condition and then distributes the power to consumers through Home Managers. Estate manager also provides a platform for suppliers to share information and data to make future decisions. This platform also helps suppliers and consumers to communication with each other timely so as to create future values.

Home manager is an interface between the mid-agent and home users, which plays a very important role in such collaborative system. It monitors the power consumption of each appliance and can also suggest consumers to make healthy consumption plans. As the frontline to the consumers, it provides chances for consumers, mid-agent and suppliers to interact with each other in different forms such as making contracts, apply power-saving schemes, information sharing, advertising and so on. More functions can be developed to fulfill the needs of consumers.

This collaborative structure provides interactive collaborative relationships among the parties. Each partner has equal right so one can't force but can influence the others' behavior in the form of signing contracts and schemes. It is possible that main supplier and the mid-agent are authorized by one party, which may be out of the consideration for the compatibility, feasibility and flexibility to develop such system from the existing electricity supply-demand structure. This kind of collaboration can also apply to our model.

Despite the structure is a virtual model but it has a very high correspond to the real condition, which has realistic significance to the real life as well as the future life. In our research, the behaviors of partners are predictable basing on the agreement in achieving social, ethical legal and environmental values.

3.2 Control Algorism in Estate Manager

As the Estate manager is central pivot in the structure, most control algorisms are applied in estate manager.

Considering the weather and geographic condition, we use solar and wind energy as the main source of auxiliary supplier. Also we added a battery as a buffering system to make the power flow from renewable energy system smooth and the battery can store some electricity in case of emergency as well.

Power from Main Supplier (P_m), Auxiliary Supplier (P_a, which contains wind turbine (P_w) and solar cells (P_s)) flow in through Estate Manager and out to the home consumers (Pc). So we have the equation:

$$P_c = P_m + P_a \quad \text{(where } P_a = P_w + P_s\text{)}$$

Estate managers calculate the demand of power in each estate and control the corresponding in-flow power. Also the amount of battery storage requirement, output power rate from renewable energy system can both be adjusted by estate managers.

Home managers also monitor the behavior of users. If some users have agreed one power saving scheme, home managers have the right to remind the user to fulfill the responsibility and make the warnings if the users get out of line.

3.3 Interface Structure

A smart metering scheme requires a smart metering management system and interface which can dynamically collect and process data; interact with partners; provide flow control; and react to the change and make decisions.

As shown in Figure 4, the smart metering system with database is operated by the mid-agent links to four different partners (Main Supplier, Auxiliary Supplier, Estate Manager and Home Manager). It builds up three interfaces between Estate Manager and the other three partners.

Estate Manager is the central pivot of the whole system which connects to up-stream and down-stream. It collects the data from suppliers and home users and it also processes the control depending on different conditions. With the help of interface, home users technically connect to both estates and suppliers, receiving electricity and interacting with administrator.

The smart metering system also provides a carrier net work and an intranet platform for partners to build collaboration with contracts and electricity schemes. Usually the Mid-agent is the intranet administrator and other members may obtain the authority to access through the agreement with administrator. Members could interact with each other in the form of sharing data, timely request-response collaboration or long-term power saving schemes.

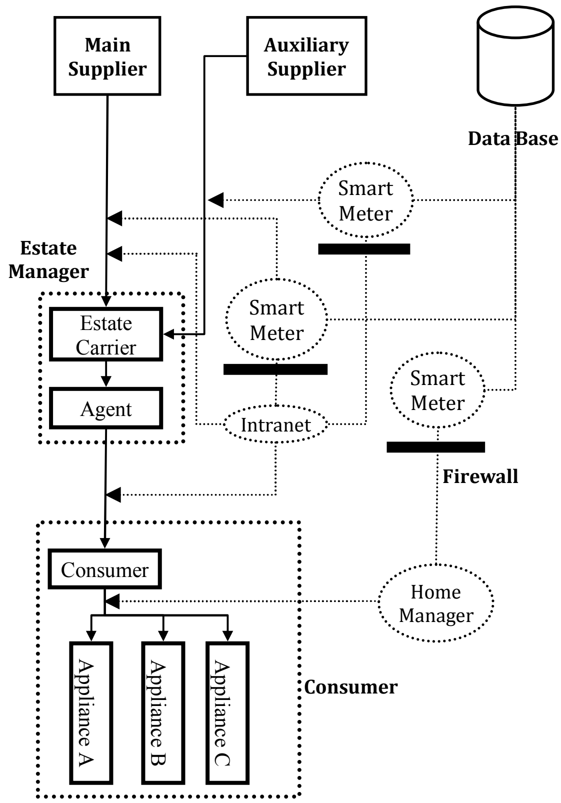

Fig.4 General Structure of Interface system

In our project, Flex Builder is used as the main interface designer to build up the surface as well as some backstage logic. Eclipse is a medium to combine the design of Flex and Java. Also a HTTP server and data base are built to guarantee the operation of the interface system.

3.4 Power Saving Schemes Development

Power saving schemes plays a very important role in the smart metering system. A good scheme will provide major incentive for the consumers to build up new cooperative relationship with suppliers. Normally, consumers can benefit from the power consumption discount if consumers fulfill the requirement of one scheme. The scheme will also help the consumers to adopt healthy power consumption cultures which can help to achieve the sustainability of the resources.

Some suitable schemes for the smart metering have been developed:

- Target Saving Scheme: Encourages monthly or seasonally target energy saving.
- Constant Consumption Scheme: Encourages consumers to consume power in constant rate.
- Peak Value Control Scheme: Encourages consumers to consume with relatively low peak value.
- THD Control Schemes: Encourages consumers to consume in a low total harmonic distortion.
- Peak Time Control Schemes: Encourages consumers to reduce consumption in peak time.
- Power Shedding Scheme (instant): Instantly request consumers to reduce consumption temporarily when suppliers meet overload.

4. SYSTEM IMPLEMENTATION

4.1 Main Supplier

Main supplier is the majority source of power in this system. It provides most of the power flows into the estate. For this unit it is the external source from the upstream.

4.2 Wind-Powered Generator

To take the convenience, auxiliary supply systems are implemented inside the estates. Wind-powered generator is one of the important parts of the auxiliary supplier, which provides the power flow internally. The location of wind turbines can be chosen in an open area with enough wind. Normally the high place on the roof of the buildings and wide areas on the island will be a good choice for setting up a wind-powered generator.

Output electricity from the wind -powered generator is in AC.

4.3 Photovoltaic System

Similar to the wind-powered generator, PV system is another internal source of power flow. It generates electricity by making use of the solar energy.

As the PV system needs sufficient sunlight, it is normally set up on the roof of the buildings. To maximize the utility of sunlight, lots of PV cells will be used. The area of PV system is suggested to be as large as possible.

With the less operation time and relatively low efficiency, the power generated by PV system is normally less than the power generated by Wind-powered generator and it also depends on the weather very much. So PV system is a supplementary power source for the system.

Output electricity from the PV system is in DC.

4.4 Battery System

A battery system is recommended after the power flows out of the auxiliary supplier. As the power rate really depends on the weather situation, the battery system can act as a buffer to smooth the power flow. It can constant the output flow under the control of administrator.

This battery system can also store the energy generated by the previous system. This storage may contribute to ease the peak time load or provide electricity in case of emergency.

Electricity generated by wind powered generator is in AC while the electricity generated by PV system is in DC. To store the electricity into the same battery system, separated transfer devices should be used before the storage.

Output electricity from the battery system is in DC.

4.5 Inverter

As the electricity for home users is in AC, there needs a device to transfer the DC from the battery system into AC. That’s why an inverter should be introduced. After the transformation, AC power flows into the estate manager.

4.6 Estate Manager

Estate manager takes the responsibility of controlling the in-flow power from upstream and distributing the power to different home users. Estate manager needs to monitor the status of the battery and decide whether to cut the power flow from the auxiliary supplier.

Estate manager locates in the intersection and act as the administrator to manage the electricity issues inside the estate.

4.7 Home Manager (Consumers)

Home managers represent consumers to join system. In the downstream, power flow through home managers to the home users. Home managers can manage the consumption and report the consumption data to estate manager and then the latter can make control with the collected data.

5. SIMULATION

As Estate Manager is the intersection of partners such as Main Supplier, Auxiliary Supplier and Consumers, our study in the behavior of the partners focuses on the interaction and control in a single estate electricity grid.

5.1 Simulation Architecture

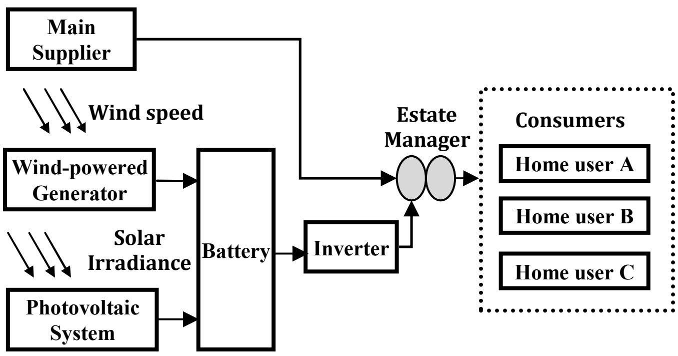

Fig.5 Architecture of the Simulation Model

The Architecture of the simulation model is shown in Figure 5. Main supplier, wind-powered generator, PV system, battery, inverter and consumers are introduced in this simulation. To test the model, we make some simplification in the simulation.

1. Home users are simplified into a single user named "Consumers", so we only need to consider one output power flow.
2. Weibull Distribution is the only distribution model used to measure the wind speed distribution. The Weibull distribution can be condensed into two parameters (A and k) which describe the shape and extent of the distribution respectively.
3. The power loss on AC-DC converting, charging and discharging in the battery system is negligible.
4. PV system outputs in rated power only for several hours around the noon.
5. There's very little loss in battery, inverter and transmission lines, the total efficiency can be represented by η_{total}
6. Main supplier provides all the rest electricity consumed to fully satisfy the total consumption.
7. After applying the scheme, consumers will fully meet the requirement for each scheme. Values created are compared between the changed consumption custom before and after the scheme application.

5.2 Theory and Equations

With the assumption above, we derived some equations which represent the relations among the components:

General System:

$$P_{main} = P_c - P_{iout}$$

Wind power:

$$P_{wind} = F(v(t))$$

PV System:

$$P_{solar} = G(I(t))$$

Battery:

$$E(t) - E(0) = \int (P_{wind} + P_{solar} - P_{bout})\, dt$$

Inverter:

$$P_{iout} = \eta_{total} P_{bout}$$

To better simulate the system's compatibility to Hong Kong, all the weather condition data used are from the government site of Hong Kong Observatory [6].

5.3 Simulation Result

One of the simulation results for the power flow in the whole system is shown in Figure 6. The behavior and power flow in the battery can be observed in Figure 7 as well.

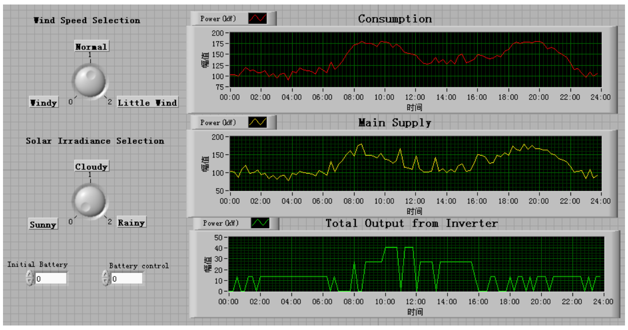

Fig. 6 Waveform for the Whole System on Normal Days

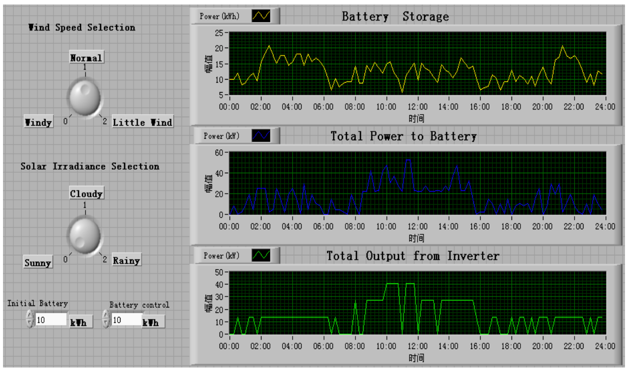

Fig.7 Waveform for the Battery System on Normal Day

From the simulations, we can demonstrate and study the behaviors of different partners. Also the relationship and collaboration can be shown very clearly.

We can observe the peak and valley of the consumption. With the help of auxiliary supplier, the power supply from the main supplier is reduced and especially in the peak time, the auxiliary can significantly release the power load pressure of main supplier.

Renewable resource generating system can save large amount of electricity. Also the application of the schemes can influence the consumers to form a healthy consumption culture.

Generally speaking, the simulation successfully simulated the behaviors of different partners. We can conclude that, this smart metering system is effective in saving energy and reducing the pressure of power load in peak time. It is feasible and sustainable.

6. CONCLUSION

This smart metering system developed provides intelligence, interaction and collaboration between suppliers and consumers. Collaboration and partnership build win-win-win-win scenarios. With the help of such smart metering system, different partners could share information and make common decisions to create totally value.

The smart metering scheme encourages a healthy electricity consumption culture which can benefit to the society, the world in the social, ethical the environmental field. It also tallies with the 21st century's concept of green and sustainable development.

In the future, when the technology of smart grid rise to a more mature level, there stands a good chance that this smart metering scheme can make big contribution to the society and the world.

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