Autonomous Cooperative Energy Trading Between Prosumers for Microgrid Systems

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Abstract— **A method of autonomous cooperative energy trading is proposed for prosumers in microgrid systems with renewable energy generation, storage and prosumer-to-prosumer energy exchange. The trading is based on policies and protocols for sharing and matching of energy schedules, including repayment of energy. Prosumer to Prosumer (P2P) trading mode and Proxy trading mode are described. Simulation results show that the proposed energy trading can increase the utilization of renewable energy, and reduce costs of energy purchase and energy storage.**

Index Terms—**energy exchange, energy trading, schedule matching, proxy, energy credit**

I. INTRODUCTION

In recent years, with the dissemination of distributed energy resources (DERs), such as PV cells and wind turbines, more and more energy users are becoming prosumers, who both produce and consume energy. Because power generation by DERs is intermittent and difficult to predict, distributed energy storage devices (ESDs), such as lithium-ion rechargeable battery storage systems, are deployed to achieve more steady supply power. Since some prosumers may have surplus energy when others' energy is deficit, cooperative distribution of energy among prosumers could also improve the balance of energy supply. However, at present energy trading is done only on large scale, for example between utilities, ISO (Independent System Operator) and ITO (Independent Transmission Operator) [1]. New mechanisms for small scale trading are needed.

In this paper we consider energy trading between prosumers in microgrid systems. In a microgrid system, prosumers can choose to connect to a utility and purchase electric power, or disconnect and operate in an island mode relying solely on its own DERs and ESDs to meet the required demand. In addition, prosumers can also trade energy with other prosumers, buying or borrowing energy from other prosumers when their own supply cannot meet their demand, or selling or lending energy to other prosumers when their own supply is surplus.

In section II we present related work. In section III we present the proposed energy trading scheme. In section IV, we present simulations of particular scenarios. And in section V we present a discussion of results and issues for the future.

II. RELATED WORK

There are several innovative projects on large scale energy exchange between districts. For example, the NOBEL project [2][3][4] is making enterprise services and energy marketplace approach to energy management in neighborhood districts. The NOBEL market is based on the stock exchange model, with the difference that the trading periods are discrete fixed-sized time slots throughout the day [4]. For energy conservation in networks, [5] gives a solution through power virtualization. At the same time, electric utilities also apply large scale energy exchange to exploit differences in variations of generation and load. Ruusunen et al. considered a power pool solution in which energy generation and consumption is monitored by the pool operator, who audits the cost and utility functions of the participants and distributes the cost savings among them [6]. Alam et al. studied cooperative energy exchange for the efficient use of energy and resources in remote communities [7]. All the above research projects are concentrating on the large energy exchange between districts and the small scale energy trading between prosumers has not been touched.

Keio University is promoting the idea of EVNO (Energy Virtual Network Operator) [8]. EVNO provides energy management services - local matching of demand-supply, autonomous scheduling based on operation policies of each power provider, and sharing of information between HEMS application programs and the EVNO management server allocation program. But EVNO has neither ESDs nor any energy delivery infrastructure. Therefore, the small scale energy trading between prosumers cannot be realized by EVNO.

Advanced office buildings now offer power infrastructure for Business Continuity Protection (BCP). For example, a 27 floor multi-tenant office building in Tokyo provides 750kVA emergency power for 48 hours for BCP of tenants. It also provides generator installation space and additional 750kVA as option to tenants for their own exclusive use. Such multi-tenant buildings can be regarded as microgrid systems, in which the tenants with DERs and ESDs are prosumers. Building Energy Management Systems (BEMS) are being promoted by many enterprises, such as NEC Corporation, to optimize the energy supply and demand control in buildings [9]. We suppose that BEMS could be extended to implement energy trading between tenants based on the proposal in this paper.

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III. PROPOSED ENERGY TRADING

The proposed trading system is composed of autonomous prosumer trading units, which we simply call “nodes”. A trade between two nodes is possible if their energy schedules match, in the sense that one has surplus energy at a time when the other requires energy.

A. Energy trade manager

Each node has an Energy Trade Manager which monitors the energy condition of the node, shares information about supply-demand schedules with other nodes, decides an energy trade schedule, and controls the energy flow in and out of the node.

B. Trade Policy

Each Energy Trade Manager has its own policy to decide the conditions for energy trading with another node, which trading mode to use (Prosumer to Prosumer trading abbreviated to P2P trading, or Proxy trading), and how to make payment (fee or energy re-payment, lump sun or installments). The policy can consider many factors, such as the category, energy status or trade history of the nodes.

C. Energy purchase or energy loan

There can be two types of trade - purchase or loan. In the case of purchase, one node pays another a fee for the transfer of energy. In the case of loan, one node receives a transfer of energy and returns energy at a later time. This requires that two-way exchange of energy is possible. A fee or an extra amount of energy can be provided as payment for the loan.

D. P2P Trade

Fig.1 shows an example of a P2P loan trading scenario. Fig. 1a shows the communication sequence and Fig. 1b shows the energy flow. Node 2 announces its energy supply and demand schedule in response to a query from node 1. Node 1 makes a specific loan order, node 2 delivers energy to node 1 at a time when node 2 has surplus, and later node 1 returns energy back to node 2 at a time when node 2 has deficit.

E. Proxy Trade

A proxy is a node with energy storage that can act as an intermediary node for asynchronous exchange of energy between trading units. In proxy trade, a proxy provides the buyer with energy at the required time, instead of the seller. Later, the proxy will receive payment or energy from the seller.

Fig.2 shows an example of a Proxy loan trading scenario. In this scenario, node B responds to a query from node A after becoming informed of the schedule of the proxy node. Node B arranges for the Proxy to send energy to node A at a time when the proxy has surplus, and then returns the energy to the Proxy at a later time.

F. Trade Protocol

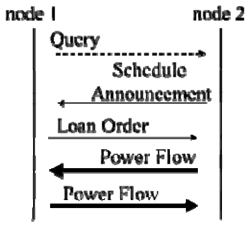
Trade is based on matching energy schedules. The key components of the trade system are as follows.

Flow Table: The future schedule showing volume of energy to be passed from one node to another at each time step is specified in a flow table.

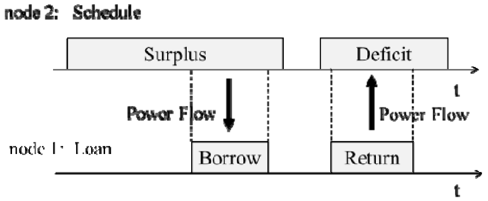
Trade Table: Each node has a trade table which shows its schedule and conditions for trading energy.

Transaction Protocol: All nodes use a common protocol to share trade table information, match conditions and execute transactions. An example of a transaction cycle is as follows:

1. Wait for next trade time
2. Exchange trade tables with other nodes
3. Select matching entries in trade tables
4. Send purchase or load orders
5. Update flow tables

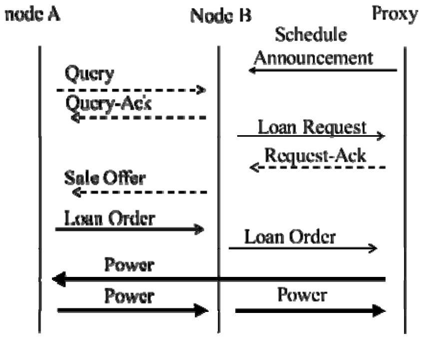


(a) Communication sequence

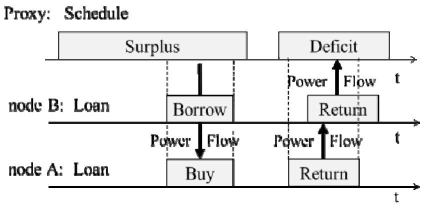


(b) Energy Flow.

Fig. 1. P2P loan trade



(a) Communication sequence



(b) Energy Flow

Fig. 2. Proxy loan trade

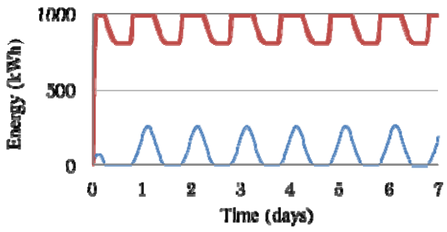
IV. EXAMPLES OF ENERGY TRADING

In this section we present examples of trading between prosumers. We present examples of both P2P trading and Proxy trading. Simulation is used to show time dependent dynamic features of trading.

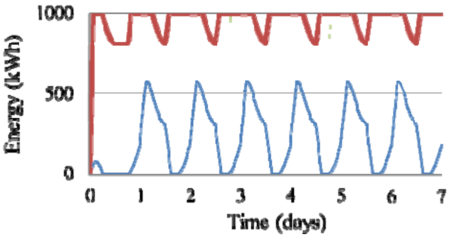
A. Example of P2P Trading

The example shown in Fig. 3 is a case in which one node (thick red line) has a higher PES rate than the other node (thin blue line). The battery capacity (1000kwh) and time-dependent demand (load) are the same in the two nodes. Renewable energy generation and energy demand vary in time with 24 hour period. The transaction protocol is executed once per day. A node requests energy if the battery energy is less than 50%, and a node agrees to provide energy if the battery energy can stay above 20%.

Fig 3(a) and 3(b) respectively show the cases with no trading and with trading. With trading, the node with low PES rate can charge more quickly by receiving power from the other node. The lending of power does not cause a drop of the lenders energy (red line) because the lender is supplying power at a time of surplus, when it is both fully charged and has PES power generation. The lender benefits from having energy repaid at a later time of lower battery energy (ie. when its PES is not generating). This example shows that energy trade can benefit both lenders and borrowers.



(a) without trade



(b) with trade

Fig. 3. Example of P2P trade: Plots show battery energy of a lender (thick red line) and a borrower (thin blue line). Lender PES rate = 10 kwh/min. Borrower PES rate = 0.8 kwh/min

TABLE I shows quantitatively how the node with the low PES generation rate achieves better overall energy supply as a result of trading. The Deficit Time Ratio is defined as the percentage of the time in each day when the battery energy is less than a certain threshold value. The threshold value for DTR is set to 33%. It can be seen that initially the DTR is 100% in all cases. Trade results in a large reduction of DFT.

TABLE I DEFICIT TIME RATIO (DTR) REDUCTION FOR BORROWER NODE WITH LOW PES RATE

Case		**Deficit Time Ratio (daily value,%)**				
trade	*generation rate (kWh/min)*	*day 1*	*day 2*	*day 3*	*day 4*	*day 5*
no	0.8	100	100	100	100	100
yes	0.8	100	62	62	62	62
no	1.0	100	93	67	50	0
yes	1.0	100	52	43	33	0

B. Example of Proxy Trading

In proxy trading, a proxy node can act as an intermediary between two nodes whose conditions are not matched for direct P2P transaction. TABLE II shows an example of a Trade Table after proxy node 3 announces trade conditions that can match both node 1 and node 2. A three-way transaction is possible with node 3 receiving from node 1 during 9:00~10:00, delivering to node 2 during 10:00~11:00, receiving from node 2 during 12:00-13:00, and delivering to node 1 during 13:00~14:00. The proxy node 3 can get 2 yen per kWh for incentive from the difference between energy sending fee and energy receiving fee in the energy trading.

TABLE II TRADE TABLE: EXAMPLE OF PROXY TRADE

Node ID	**Flow Attributes**			**Commerce Attributes**	
	send/ receive	*time*	*volume (kWh)*	*fee (yen/kWh)*	*payment method: time*
1	send	9:00 -10:00	2	20	repay energy: 13:00-14:00
2	receive	10:00 –11:00	2	22	repay energy: 12:00-13:00
3	receive	9:00 -10:00	2	20	repay energy: 13:00-14:00
3	send	10:00 –11:00	2	22	repay energy: 12:00-13:00

Fig. 4 shows another example of proxy trade. The thick red line shows the battery energy of a node with PES but no load. The thin blue line shows the battery energy of a node with no PES and low capacity. The dotted black line shows the battery energy of a node acting as proxy, receiving energy from the first node and delivering energy to the second node.

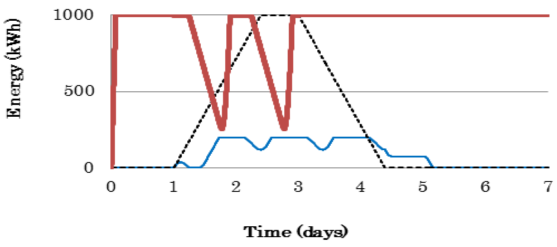


Fig. 4. Example of Proxy trade: Loan from node with high PES (thick red line) to node with no PES (thin blue line) via a proxy node also with no PES (dotted black line)

V. DISCUSSION AND CONCLUSIONS

The examples showed that the proposed trading allowed prosumers to increase their energy supply by trading surplus energy in the microgrid. This means that the amount of energy that needs to be purchased from the utility grid can be reduced. At the same time, the cost of equipment can also be reduced if prosumers can meet their demand with less storage capacity due to buying or borrowing energy from other prosumers.

For the realization of proposed trading method, two requirements should be satisfied. One is the technology requirement. The deployment of switches and power-lines should support two-way energy transmission. The other is economic viability. The scheme should be economically viable in the sense that cost of energy obtained by trading inside the microgrid is less than the cost of energy from the utility grid.

As for technology requirement, deployment of switches and power-lines supporting two-way energy transmission is a hot area of development, and it can be expected that such infrastructure as [10] will become widely available in the near future.

As for economic viability, useful indicators are levelized cost and grid parity. Levelized cost considers all necessary factors, such as power generation cost, power storage cost and power transfer cost, contributing to cost over the lifetime of the system. So-called “grid parity” is achieved if the levelized cost is less than the cost of grid energy. Due to improvements in technology, there is a rapidly increasing number of locations throughout the world that have the potential to lower the levelized cost and achieve grid parity [11,12]. According to the Japanese government organization NEDO the grid parity in Japan for households is 23yen/kWh [12]. According to [12], in this paper we assume the levelized cost of energy generated in the microgrid is 20yen/kWh. Therefore 3yen/kWh is the economic benefit for the proposed trading. The results shown in Section IV also apply to future stages of the energy roadmap in Japan. For example, for 2020~2025, when it is expected grid parity can be achieved for commercial electricity at 14yen/kWh, it is reasonable to assume that levelized cost of energy generated in microgrids could be 11yen/kWh [12], which is 3yen/kWh cheaper than the grid parity. Our results for proxy trading also show that if the difference between levelized cost and grid parity is sufficiently large, proxy nodes can get economic benefit from buying and selling at intermediate prices.

Examples of areas where microgrids and energy trading could be feasible in the near future are multi-tenant buildings, business-park or factory-parks. A tenant in a multi-tenant building can be a prosumer, and a building host can be a prosumer or a proxy. Energy sharing between tenants in a multi-tenant building or between multi-tenant buildings can realize the proposal method. Multiple different businesses or factories co-located in a business-park or factory-park will share infrastructure. In the long-term, sharing and trading by individual homes can also be expected to become economically feasible.

Besides the economic benefits to prosumers, the proposed energy trading can also reduce CO2 emissions, by increasing utilization of renewable energy. The combination of this trading scheme with the rapidly advancing schemes for trading in energy credits will be an important topic for the future [13].

In conclusion, the proposed energy trading can increase the utilization of renewable energy, and reduce costs of energy purchase, energy generation and energy storage. Advances in technology for more efficient generation, transmission and storage of energy are expected to further reduce the levelized cost within microgrid. This means that there we can expect a strong growth in the economic incentive for implementing such cooperative energy sharing in microgrids.

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