An Internet of Energy Based Framework of Aggregator for Power Allocation Among Residential Users

Saher Javaid, Yuto Lim, Yasuo Tan
Graduate School of Advanced Science and Technology,
Japan Advanced Institute of Science and Technology (JAIST), Japan

Abstract—Recent advancements in renewable energy sources and Internet of Things (IoT) technologies has urged energy management to enter the era of Internet of Energy (IoE). The development of renewable and distributed power sources along with the change in power market structure due to deregulation require a new agent to manage these resources in the most efficient way. An aggregator can manage the supply side and the demand side in order to provide some services to the grid as well as to consumers. This paper proposes an IoE based framework of aggregators for power allocation among residential users in the presence of distributed power sources. The novelty of our proposed framework rests in (i) power assignment criteria based on detailed residential demand profile (ii) power supply from multiple power sources based on their capacity limitation (iii) consideration of communication delay.

I. Introduction

The continuous growth of power demand and the global concerns to reduce gas emissions calls for a significant increase of power generations from renewable power sources. Two key issues in creating a sustainable and energy-efficient society are decreasing peak power demands and increasing the penetration of renewable power sources. In order to achieve a reliable operation of the power system, supply and the demand have to be balanced all the time [1]. With IoE, huge distributed energy sources, storage facilities, and IoT technologies are able to share "energy" just in the same way as "information" [2]. New resources such as distributed generation systems and storage systems have been gradually integrated to the grid and for the next years the integration tendency will increase.

These resources require a new agent called "aggregator" to manage them effectively. The aggregator coordinates the end users and tries to achieve a group-level objective (e.g., power balancing, reductions in gas emissions to provide environment friendly system). It is placed between the demand side consisting of a group of consumers and the distribution operator. It provides the distribution operator cumulative energy available, from storage and renewable power sources at any time during the day. In [3], hierarchical framework for coordination between distributed sources and demand response is introduced using aggregators. However, the power assignment criteria and consideration of communication delay is not considered which is the novelty of our proposed work.

In this paper, we consider an electric market, which consists of an electric utility operator, a set of aggregators, a set of residential users, and local power generation/storage systems as depicted in Fig. 1(a). Each residential user participates in the market through a specified aggregator after agreeing to the contract, i.e., residential users cannot move between

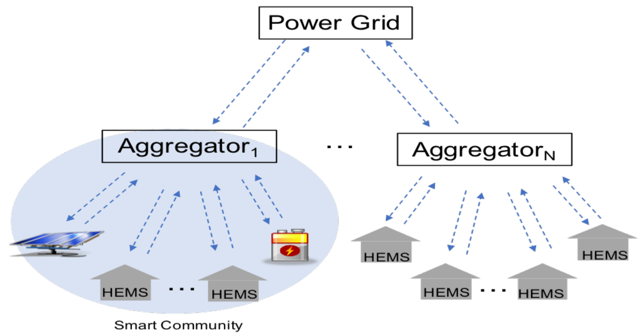

Fig. 1 (a). Illusion of the concerned IoE based framework of aggregators (Multiple Aggregators)

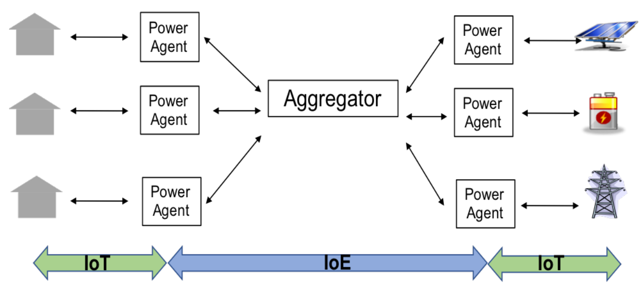

Fig. 1 (b). Single Aggregator.

aggregators. An explicit framework of an aggregator for power allocation among residential users is the main concern of this paper as shown in Fig. 1(b). The aggregator allocates power while keeping the continuous checking of the efficiency of power generating/storage systems and power flow streams are controlled based on the burden on each power source.

II. Proposed System Overview

The basic operation of proposed system starts (i) when a residential user wants to change its power consumption (i.e., increase or decrease consumption), the attached power agent sends *power consumption profile* to the aggregator (ii) Upon receiving profile from residential user, the aggregator agent broadcasts a *start negotiation message* to all power sources and residential users (iii) After that, all power agents associated with users and power sources send their complete detailed information to the aggregator agent to update about the latest situation (iv) Aggregator agent then starts negotiation process, which decides how much power should be allocated to the residential user based on available capacity of a power source, (v) Then, a *power allotment message* is send to the requested residential user and the available power source.

III. Framework of Aggregator for Power Allocation

There are two key parameters (i) detailed power consumption profile of residential user which differs from user to another, (ii) load factor profile of each power source to show the capacity of its power supply.

A. Power Consumption Profile of End-User

We assume that each residential user is equipped with power agent. The role of this power agent is to measure, transmit, and control user's consuming power, and also to coordinate with the aggregator. All power agents are connected with the aggregator agent through a wireless communication infrastructure.

The intended time cycle for the operation of the user i divided into timeslots $t = \{1, 2, \dots, T\}$. Given that each residential user is assigned to an aggregator through a contract, for each user $i \in N$, let PC_i^t denotes the amount of power consumed by user i in timeslot t. For each user, $i \in N$, and each timeslot, $t \in T$, we define the power consumption interval I_i^t as,

$$I_i^t = [PC_{imin}^t, PC_{imax}^t] \quad (1)$$

and the consumed power PC_i^t has to satisfy $PC_{imin}^t \le PC_i^t \le PC_{imax}^t$. The power consumption profile of a user is different from other users that changes from a time interval to another. The minimum power consumption limit, PC_{imin}^t, has to be satisfied all the time. This limit represents the power consumption of consumer electronics which need to be turn ON during the day e.g., refrigerator. The maximum power consumption limit, PC_{imax}^t, shows the situation when all consumer electronics are turned ON.

In our proposed system model, the aggregator collects power generation and consumption information from power agents attached with residential users and power sources. The aggregator has total power available to distribute among all residential users, P_{total}^t, which can be calculated as,

$$P_{total}^t = P_{grid}^t + P_{batt}^t + P_{pv}^t \quad (2)$$

Thus, the remaining power can be computed as,

$$RP^t = P_{total}^t - \sum_{i=1}^{N} PC_i^t \quad (3)$$

where, PC_i^t is the actual power consumption of residential user i at time t. On the other hand, we assume that each residential user has its own maximum power consumption, and it behaves on the first order state equation given by,

$$\dot{PC_i^t} = -a_i . PC_i^t + b_i . u \quad (4)$$

where,

$$b_i . u = \begin{cases} a_i . PC_{imax}^t & if \;\; S_i^t + PC_i^t \ge PC_{imax}^t \\ a_i . (S_i^t + PC_i^t) & if \;\; S_i^t + PC_i^t < PC_{imax}^t \end{cases}$$

with

$$S_i^t = \frac{RP_i^{(t-\tau)}}{l}$$

Note that, in our first order state equation model, $-a_i$ is the slope of the marginal benefit and should be predetermined and b is the initial value of the marginal utility when user's power consumption is zero. Thus, this variable also distinguishes a user from the other. The value, $\frac{b}{a}$, is the consumption value at which the utility function is maximum. In our model, $S_i^t + PC_i^t$ is assumed as available power allocated to each residential user, where S_i^t is the delayed version of the remaining power divided by the fairness index or power divider, l, and τ is the communication delay. This represents the time when aggregator receives consumption profile and assign computed allocated power to the requested residential user.

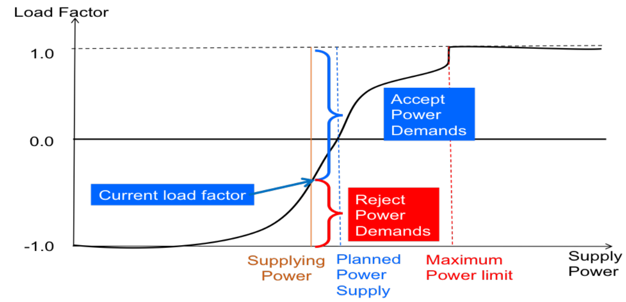

Fig. 2. Load Factor Function of power source.

B. Load Factor Profile of a Power Source

A power agent attached with power source is responsible for measuring and controlling power supply of the attached power source. Let PS represents a set of power sources indexed as, $PS_j = \{PS_1, PS_2, \dots, PS_M\}$. Each power source agent designs a load factor profile with detailed characteristics of attached power source. Load factor defines the capacity or efficiency of a power source in supplying power. Let LFF_j denote a load factor function of jth power source as, $LFF_j = \{< ID, LFF_j, current\_LF >\}$ .Where, ID shows the unique identification number of a power source, LFF_j represents load factor function of the power source, $current\_LF$ indicates current load factor at that time. In Fig. 2, horizontal axis shows power supply whereas, vertical axis shows load factor which uses continuous value ranges from -1 to 1. The load factor curve implies that the power demands from residential users whose consumption profiles are less than the current load factor of a power source are rejected. Note that, load factor is a monotonically increasing function. That is, the load factor increases as power supply from a power source increases.

IV. Concluding Remarks

This paper proposed a framework of aggregator for power allocation among residential users. The introduction of power agents brought a paradigm shift in the analysis of power consumption and generation. In this paper, we study the effects of power agents that provide access to power supply and demand, but with some communication delay. The main objectives of this paper are to analyze detailed power consumption and supply profiles for power allocation. To reach above objectives, we analyzed the proposed system in simulation environment.

References

[1] K. Rahbar, J. Xu, and R. Zhang, "Real-time energy storage management for renewable integration in microgrid: An off-line optimization approach," IEEE Trans. on Smart Grid, vol. 6, no. 1, pp. 124–134, Jan. 2015.

[2] Y. Guo, M. Pan, Y. Fang, and P. Khargonekar, "Decentralized coordination of energy utilization for residential households in the smart grid," IEEE Trans. on Smart Grid, vol. 4, no. 3, pp. 1341– 1350, Sept. 2013.

[3] D. Wu, J. Lian, Y. Sun, T. Yang, and J. Hansen, "Hierarchical control framework for integrated coordination between DERs and demand response" eprint arXiv:1701.01913, 2017