RAMP: Impact of Rule Based Aggregator Business Model for Residential Microgrid of Prosumers Including Distributed Energy Resources

Mohammad Abdullah Al Faruque
Department of Electrical Engineering and Computer Science
University of California, Irvine, Irvine, California, USA
E-mail: {alfaruqu}@uci.edu

***Abstract* —This paper discusses an economically profitable way to deploy a residential microgrid incorporating a new market entity "residential aggregator" between the prosumers[1] and the Utility. In this residential microgrid, the residential aggregators will have better negotiating capabilities (e.g. in the DR programs) in the electricity market and therefore will be able to bring economic advantages to all participating stakeholders (prosumers, Utility, and aggregator). However, to implement such a microgrid, various rules regarding electricity pricing will need to be put in place. This paper highlights such rules and their impacts, and two example use cases are used to show the different types of distributed energy resources that would be required for profitable residential microgrid deployment.**

***Index Terms*-- Residential Microgrid, Residential Aggregator, SREC, Distributed Energy Resources, Demand Response**

I. Introduction And Related Work

A microgrid is a localized and semi-autonomous group of distributed electrical energy resources (storage and generators such as Photovoltaic) and loads (appliances) that connects to a traditional power grid (macrogrid). During certain physical and economic conditions, it may disconnect from the power grid, and operate autonomously (island power) [1, 3, 5]. Besides various active research and demonstration activities to deploy a microgrid at military installations, critical infrastructure areas (e.g. hospitals), commercial and university locations, and remote geographic areas, deploying a microgrid at the residential domain has become a necessity today [2, 3, 5, 6, 16]. The technologies that are driving the deployment of residential microgrids are: Electric vehicles that feature *Vehicle-to-Grid* (V2G) and *Vehicle-to-Home* (V2H) power flow technologies [10], roof-top photovoltaic, residential-home/building-scale energy storage, smart appliances, and *Home Energy Management* (HEM) systems (Figure 1) [2].

Besides the well-known advantages of the microgrid, its success (especially for the residential domain) highly depends on the economic advantages of participating stakeholders (Utility, prosumers, etc.). In most of the western countries today, the monopolized electricity market structure has been transformed to a more competitive structure including the aggregators [11] due to the market de-regulation. This de-regulation creates an open market for energy distribution where competition is intense and profit margins are relatively small [18]. Therefore, policies, methods, regulations, and technologies are required to make this paradigm shift reliable, efficient, and scalable, as well as make its participating stakeholders profitable for long-term sustainability [16].

Generally, aggregators combine prosumers into a purchasing single unit for the purposes of negotiating the purchase of electricity from the electricity market [7, 9]. Also, aggregators function to negotiate *Demand Response* (DR) and home generation of their renewables in the electricity market. In this paper, "*residential aggregators*" are considered to combine multiple residential prosumers with their in-house renewable generation, energy storage (including EV batteries), flexible electricity consumption (shifting the load through storage), participation in the electricity market through DR program, and other innovative services for the residential microgrid.

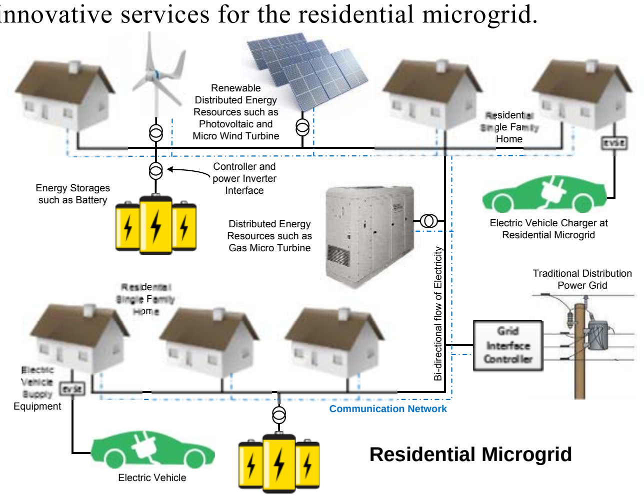

Figure 1. An exemplary conceptual residential microgrid

In general, the aggregator business model has been already successful for both the commercial and industrial market domains due to the possibility of saving a larger amount of electricity through DR during peak load time [8, 9]. For example, aggregators like EnerNOC consider good customers only those who can shed more than 100 kW of electricity during the DR period [7]. Therefore, it can be clearly seen that there is a direct correlation between the

[1]Besides consumption of electricity from the Utilities, currently, residential households produce renewable energy which feeds-in to the macrogrid. The consumers have become active producers and therefore may be seen as prosumers [16, 17].

amount of power that may be negotiated during DR and the business interest of the aggregators. To increase the negotiating capability of the prosumers, this paper discusses the details of forming a residential microgrid.

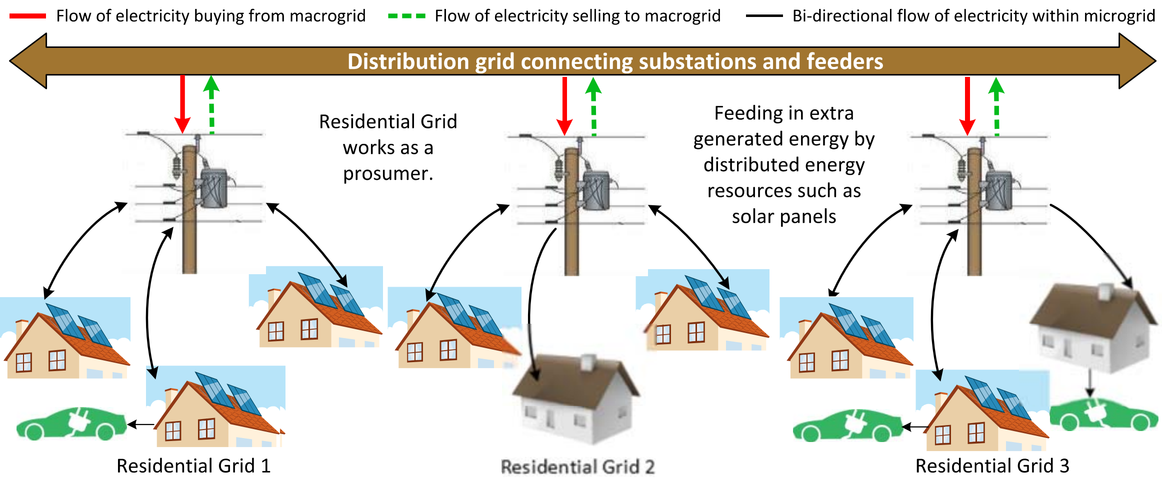

Figure 2. Existing residential electricity business model

To the best of the author's knowledge, there is no deployed residential microgrid that is economically profitable for all the participating stakeholders due to lack of proper business rules and/or policies in place. Therefore, in the scope of this paper, a *Rule-based Aggregator*[2] *Business Model for Residential Microgrid of Prosumers* (RAMP), some recommendations to change the policy for the residential electricity business model, and cost-benefit analysis based on this adapted business model are discussed.

II. CONTENT OF THIS PAPER

1) This paper discusses a profitable and practical deployable microgrid architecture for the residential domain electricity distribution grid. Two different scenarios of residential microgrids are show-cased: the *single-unit housing complex* (typically single house → single owner) and *the multi-unit clustered & shared housing complex* where there is a single owner but many renters and distributed energy resources.

2) A profitable new market entity termed as "residential aggregator" (see Figure 3) between the Utility and the group of residential houses forming the residential microgrid is presented. The financial advantages of the participating stakeholders through using the proposed rules and business policies are analyzed. Finally, it is argued that residential microgrid deployment will be economically profitable and therefore further research activities are required to solve additional challenges, e.g finding the minimum number of prosumers to make all the participating stakeholders profitable compared to the capital and the operational cost.

III. RESIDENTIAL DISTRIBUTION MODEL

The current business model for the residential electricity market between the Utility and the prosumers is shown in Figure 2. Typically, the owner of a household receives some financial advantages (e.g. tax benefits from the government for installing the renewables). In addition to this support, there are various other ways to finance the installation (solar cells, inverters, etc.) of the renewables, e.g. temporary leasing. Guaranteed grid access and long term commitment to the Utility companies are also required since the house would still be connected to the macrogrid; this is necessary in times when the DRs of the microgrid are not sufficient for meeting the power demands of the household. However, when this happens, the produced electricity from renewables is compensated by the consumption from the macrogrid. If additional electricity is produced then it is feed-in to the Utility grid with a predefined price (typically less than the cost to buy electricity from the grid). This is termed as *Feed-in-Tariff* (FiT) policy mechanism designed to encourage the adoption of renewables [12].

Moreover, the electricity rate may depend on state and federal regulations, the Utility's business model, place of installation, size of the installation, technology used, etc. For example, various states within the USA allow solar system owners to recover their investment in solar by selling their *Solar Renewable Energy Certificates* (SRECs) [13] through spot market sales or long-term sales in conjunction with state and federal incentives. SRECs represent the environmental attributes of a solar facility, and are produced each time a solar system produces one *MegaWatt-Hour* (MWh) of electricity. The additional income received from selling SRECs increases the economic value of a solar investment and assists with the profitability of the solar technology. The current business model for the residential electricity market (no residential aggregator in place) suffers from the following major shortcomings:

- The residential prosumers are a very small electricity entity for the electricity market; therefore it is not economical for them to participate individually.
- The cost of produced renewable electricity provided to the prosumers by the Utilities is not sufficiently

[2]The *residential aggregator* may be a co-operative formed by the house owners or a different individual.

encouraging enough to install more renewables. Moreover, if the prosumers want to install more renewables they are not typically allowed by the Utility to do so due to their little negotiation capability with the Utility.

The existing aggregators available for the industrial and commercial domain are not interested in the individual residential prosumer as their electricity consumption is very low and their chance of saving electricity during DR is also not profitable for the aggregator. Furthermore, prosumers have less motivation to join the DR program individually to further benefit from the emerging electricity business model due to the higher initial cost to upgrade their appliances, home automation devices, internal grid, etc.

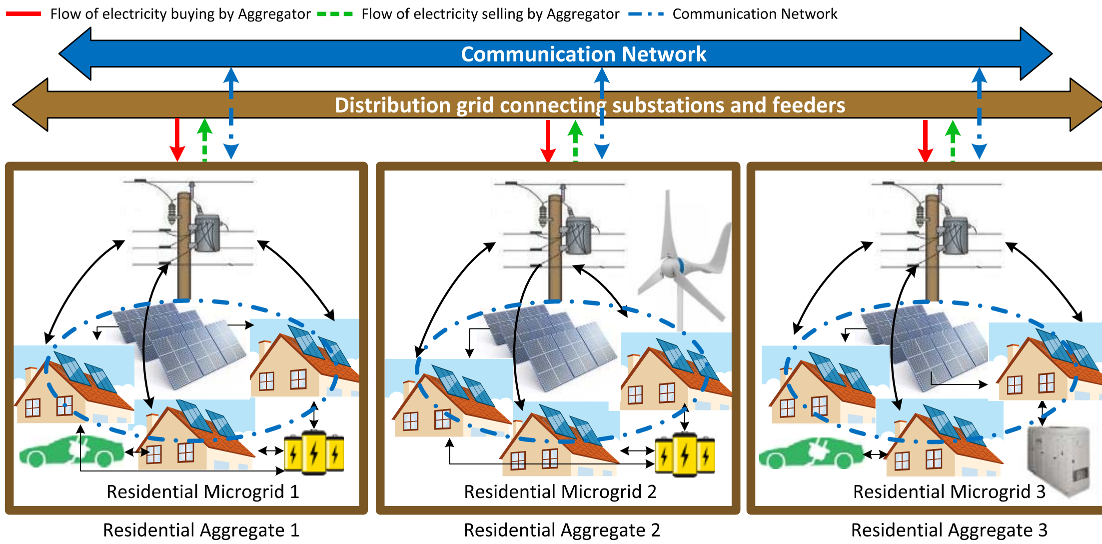

Figure 3. Aggregator-based residential microgrid model

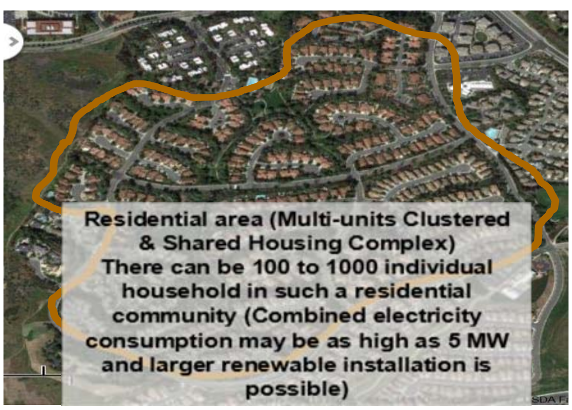

Figure 4. An example view of multi-units clustered & shared housing complex (CA area)

IV. Residential Microgrid

Besides a connection to the macrogrid, residential microgrid typically have the following distributed energy resources and software & hardware components: distributed generation units (renewables), energy storage including EV batteries supporting V2G and V2H technologies, power electronics devices, (e.g. inverters, protection devices), smart appliances that may communicate with the system, microgrid management software, HEM, smart meters, grid monitoring infrastructure that includes both software and hardware, communication infrastructure, and different types of controllers (local and microgrid level controllers). Therefore, deployment of a residential microgrid requires capital and operational investment by the staheholders.

A. Residential House Types

In this work, two types of residential complexes are primarily considered similar to the complexes described in [16], 1) *multi-units clustered & shared housing complex*: build based on a commercial basis (single owner → multiple renters) and 2) *single-unit housing complex*: (each house is typically owned and/or occupied by only one family). However, the presented analysis may be generalized for other types of residential complexes.

1) Multi-units Clustered & Shared Housing:

Figure 4 presents a very typical *multi-unit clustered & shared housing complex* (a Google Maps view of the anonymous CA area). In such a residential complex, generally there is a single authority that owns and manages all the apartments and lets them to individual families by renting. The number of households typically varies from 100 to 1000 in such a complex. Some observations from the existing systems are as follows:

- The upgrade of the electric system of any household may only be done by the owner.
- Each renter has an individual contract regarding his/her electricity, as well as other Utilities, e.g. water, gas with local representative entities (e.g. Edison [15]).
- The owner of the community may install renewables, e.g. rooftop solar cells, biogas, and etc.
- The average load needed by each house may vary from 4 to 5 kW [6]. Therefore, the total load from a 1000 household size community may be between 4 MW to 5 MW. This may be a good candidate to attract an aggregator

business entity in between the prosumers and the Utility. This larger amount is also a good candidate for DR and other co-operative functionalities within the residential microgrid, e.g. collaborative e-car charging [14].

Figure 5. An exemplary view of single-unit housing complex (CA area)

2) Single-unit Housing:

The most common types of residential houses are single unit housing complexes, where the owner is typically the resident of the house. Figure 5 demonstrates such a residential complex in an anonymous area of CA. Multiple such single-unit houses sharing neighboring step-down transformers may form a microgrid where an aggregator business model may be formed. The residential aggregator for such a housing complex may be the house owners themselves through forming a co-operative (details of such a co-operative are out of the scope of this paper). The load from each house may be as high as 10 kW [6]. It is assumed that most of the houses in this microgrid will have renewables (mainly solar).

B. Rule Based Business Model

1) Required Policies for Profitability

Various existing and/or new policies required for the presented residential microgrid are as follows:

• A guaranteed grid access and long term commitment with the Utilities and the residential aggregators are required as the houses are connected with the macrogrid.

• A guaranteed electricity price that must be at least similar to what an individual prosumer would receive from the Utility.

• Residential aggregators have the ability to join the electricity market to negotiate with the Utility through DR.

• When the microgrid is capable of producing more electricity (this should be assumed normal) than average consumption, residential aggregators are bound to take the business risk by participating as a producer in the electricity market or by storing the energy and shifting the load. The end prosumer will never be risked on price. Their financial advantages must be guaranteed.

2) Rules of the Business Model

The business rules to make the residential microgrid profitable for all the participating stakeholders are:

Rule 1: □□□ < □□□ : the price of the renewable electricity prosumers receive from the residential aggregator will be higher than the price received from the Utility.

Variables used for the business rules
▪ *Elec. price for prosumers(p)from Utility =* □□□
▪ *Elec. price for aggregators (a) from Utility =* □□□
▪ *Renew. elec. price utility pays to prosumer (p) =* □□□
▪ *Elec. price for prosumers (p) from aggr. i =* □□□□□
▪ *Renew. elec. price agg. pays to prosumer =* □□□□□
▪ *Renew. elec. price utility pays to agg. W/O DR =* □□□□
▪ *Renew elec. price utility pays to agg. during DR =* □□□
▪ *Elec. price paid by agg. j to buy from aggregator i =* □□□
▪ *Elec. price paid by agg. i to buy from aggregator j =* □□□
▪ *Avg. daily elec. consumption by single house k =* □□□□
▪ *Avg. daily elec. production by single house k =* □□□□
▪ *Part of produced elec. that is supplied to house k from the aggregator i installed storage S =* □□□□
▪ *SREC cost received for renewable electricity generations one megawatt-hour (MWh) =* □□□□□□□
▪ *Amount of elec. feed-in to utility during the DR =* □□□□
▪ *Amount of energy stored in a Storage S =* □□□
▪ *Capital investment by the aggregator a is* □□□□□
▪ *Capital investment by the prosumer p is* □□□□□
▪ *Maintenance cost for DR, m =* □□□□□

Rule 2: □□□ >= □□□□□ : the electricity price prosumers receive from the residential aggregator *i* will not be more than the price they had been paying to the Utility and other houses who are not participating in the aggregator model is paying to the Utility during that time-frame.

Rule 3: □□□ >= □□□ : the electricity price residential aggregators receive from the Utility must be at least similar to what an individual prosumer will receive.

Rule 4: □□□ > □□□□ : the price of electricity that the residential aggregators may sell to the Utility during the peak load time will be higher than the normal flat price that Utility pays to the residential aggregator.

Rule 5: □□□ <= □□□□: mostly both (residential aggregator and prosumer) will receive the same price with/without aggregator presence from the Utility for their produced additional electricity. Regulation will monitor that Utility does not obstruct the aggregator business.

Rule 6: □□□ >= □□□ + □□□□: the energy storage including EV batteries must be sufficient to accommodate intermittency of the renewables.

Rule 7: □□□ >= □□□ : it may be also possible to trade electricity among neighboring residential aggregators.

C. Benefits of the Micorgrid Stakeholders

1) Utility benefit

To cover the peak load demand (typically between 2 PM to 6 PM on a normal working day [8]) and to keep the reliability of the power flow, it requires new power generation plants to be built. To avoid the higher building cost of electricity generation plants to support only the peak load time, DR programs manage the peak load by shedding the pre-selected (also dynamic selection is possible using advanced control algorithms and communication infrastructure) loads at the demand side in exchange for financial advantages to the prosumers has been seen to be a very profitable technology for the Utilities. Therefore, the proposed systematic way of integrating the residential prosumers in the DR program will directly benefit the Utilities economically by not investing on new infrastructure just to support the peak load demand. However, as the profit margins for the Utilities are typically high, to encourage the participating prosumers, the capital and operational costs for the residential microgrid, e.g. □□□□ and □□□□ may be paid by the Utility.

2) Residential aggregator benefit

This is a new business entity that operates between the Utility and the prosumer. The investment of the residential aggregators in the energy business may be different based on the types of microgrid and the aggregators (prosumers may also form a co-operative that acts as the residential aggregator). This paper assumed there will be a sufficient amount of energy storage including the possibility of using EV batteries to overcome the intermittency behavior of the renewables. This energy storage will help the residential aggregators to shift the load and to supply additional electricity to the macrogrid during peak demand. In the case of the *multi-units clustered & shared housing complex* model (see subsection 4.A.1), the residential aggregators may also take the responsibility to install the renewables to the community. The profit of the residential aggregator may mathematically be formulated as follows:

Let us assume that there are *n* numbers of prosumers where each prosumer consumes □ kW.h of electricity per day. Now also assume each prosumer has the ability to produce □ kW.h amount of renewable electricity. Therefore, the total renewable energy may be calculated as (*n* X □). In the following calculations, it is assumed that □□□□ will be paid back over couple of years of successful operation and maintenance cost for DR, □□□□ will be very negligible or shared with the Utility. Several scenarios to calculate the profit function (π) for the residential aggregator is shown as follows:

- Electricity storage, *S* is there, load shifting is possible, no renewable electricity is fed-in to the Utility, □ < □ and □ = □.

$$\pi = n\ X\ ((\square\ X\ (\square\square\square\ \square\ \square)) - (\square\ X\ (\square\square\square\ \square\ \square)) - ((\square - \square)\ X\ \square\square\ \square\ \square)) \quad (1)$$

- Electricity storage, *S* is there, load shifting is possible and the residential aggregator is participating in the DR program and therefore, electricity is fed-in at a higher price to the Utility, □ < □, and □ = □ + □ and □ < □.

$$\pi = n\ X\ ((\square\ X\ \square\square\square\ \square\ \square\ \square) - (\square\ X\ \square\square\square\ \square\ \square\ \square) - ((\square - \square)\ X\ \square\square\ \square\ \square)) + (\square\ X\ \square\square\ \square) \quad (2)$$

- Electricity storage, *S* is there, load shifting is possible and the residential aggregator is not participating in the DR program but additional electricity is fed-in with regular price as others to the Utility, □ > □, □ is fed-in to the Utility from the residential aggregator and □ = □ + □.

$$\pi = n\ X\ ((\square\ X\ \square\square\square\ \square\ \square\ \square) - (\square\ X\ \square\square\square\ \square\ \square\ \square) - (\square\ X\ \square\square\square\ \square)) \quad (3)$$

This case is the least profitable for residential aggregators.

- Electricity storage, *S* is there, load shifting is possible and the residential aggregator is participating in the DR program, therefore, additional electricity is fed-in with higher price to Utility, □ > □, □ is fed-in to the Utility from the residential aggregator during DR and, □ = □ + □.

$$\pi = n\ X\ ((\square\ X\ \square\square\square\ \square\ \square\ \square) - (\square\ X\ \square\square\square\ \square\ \square\ \square) + (\square\ X\ \square\square\ \square)) \quad (4)$$

This case is the most profitable scenario for residential aggregators (see Figure 6).

- This case is particularly valid only for the *multi-units clustered & shared housing complex* model where residential aggregators have installed renewables by agreement with the owner. Electricity storage is there, load shifting is possible, and the residential aggregator is participating in the DR program, therefore, additional electricity is fed-in with higher price to the Utility grid, □ > □, □ is fed-in to the Utility from the residential aggregator during DR and □ = □ + □.

$$\pi = n\ X\ ((\square\ X\ \square\square\square\ \square\ \square\ \square) - (\square\ X\ \square\square\square\ \square\ \square\ \square) + (\square\ X\ \square\square\square\ \square) + (\square\square\square\square)) \quad (5)$$

- Similar to Equation 5, in Equations 1, 2, and 3, (*n* X □□□□) may be added for the *multi-units clustered & shared housing complex* model.

It is argued in this paper that the profit margin presented above for the residential aggregators will be motivating enough to recover the capital investment (□□□□) quickly.

3) Owners benefit from multi-units clustered & shared housing

In general, the Utility is paid for by the renters in such a residential complex. Therefore, the owner may not be interested in participating in this model but the innovative incentives may motivate the renter to join this business model. Due to renewables, the utility cost for the renters will be reduced considerably. Therefore, the owner can easily get more renters by putting this feature in their campaign and also owner can increase their rent slightly to get a small share of the renters' savings.

4) Renters benefit from multi-units clustered & shared housing

Renters will be able to reduce their utility bill as there must be commitment from the residential aggregator to provide electricity in lesser price compared to the Utility price. Residential aggregators may also take the direct responsibility of the DR (e.g. direct load control) and spend for the necessary building upgrades. In such a scenario, renters do not need to spend for the initial DR hardware (□□□□ and □□□□) and therefore, they will economically benefit from their reduced utility bill.

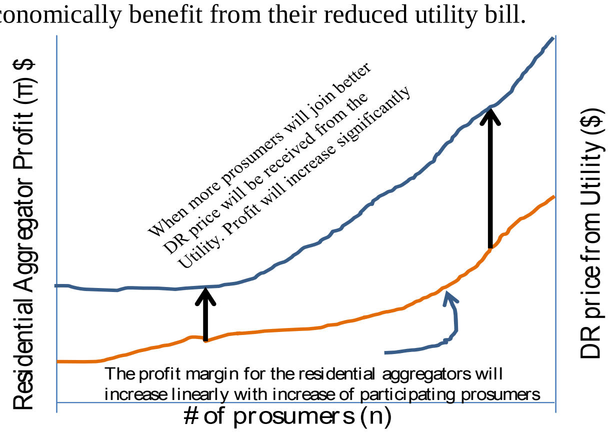

Figure 6. Trend graph on the profitability of the residential aggregators

5) Prosumer benefit in Single-unit housing

The owners benefit from the microgrid architecture is that they get higher price from their produced renewable electricity. Therefore, the utility cost is reduced for individual household in this model. Participating through residential aggregator in the electricity market, residential aggregator and prosumers get more negotiating capability.

6) Opt out scenarios by the participating stakeholders

Though this paper anticipates profitability for all the participating stakeholders, during the operations of the residential microgrid due to maintenance cost, prosumers or the residential aggregator may want to opt out from the agreement. Therefore, regulations and rules must allow such mechanisms of opt out. However, detailed discussion to find the breakeven point is out of the scope of this paper. Our future work includes modeling such a residential microgrid in GridMat [19] and simulating various scenarios to find out various required parameters for such a residential aggregator-based microgrid model.

V. CONCLUSION

This paper discusses a profitable and deployable business model for a residential microgrid. Various rules and policies in the electricity markets are discussed to demonstrate when and how a residential microgrid may be profitable. This study will benefit the research activity that is focused on developing advanced control and demand side energy management techniques for the residential microgrid. Moreover, the author understands that this study also requires further investigation in the presence of real use cases and the financial markets.

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