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Luke Marshall

Allocation Rules and Meter Timing Issues in Local Energy or 'Peer to Peer' Networks

Luke Marshall[1], Anna Bruce[1], Iain MacGill[2]

[1]*School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney NSW 2052, Australia*

[2] *Centre for Energy and Environmental Markets and School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney NSW 2052, Australia*

E-mail: luke.marshall@student.unsw.edu.au

Abstract

The growing adoption of distributed energy resources (DERs) across Australia may represent the start of a transition of Australia's power system from a centralised generation model towards an interconnected set of embedded microgrid systems. In these systems, local trading of coincident generation and consumption is being explored, with the idea that this would encourage consumer engagement, provide more choice, and incentivise reduced use of networks (via increased balancing of loads and generation locally). However coincidence of generation and load over short time frames, and hence network benefit, can be difficult to determine using existing metering systems.

There are many sites undergoing trials to determine how energy flows can be efficiently monitored and accounted for in microgrid systems. At the current time, commercial metering is generally performed on time scales greater than thirty seconds, with most metering systems measuring net flows on half-hourly intervals. This represents a barrier to accurate accounting, since the time at which nodes generate and consume energy within a wide metering period is not known. As a result, end-users may face effective penalties or avoid charges that would accrue to their generation or consumption profile under more accurate accounting.

Accurate accounting for the economic benefits of embedded microgrids that result from either reductions in external network use or contributions to improved reliability, rely on sub-second level timing, and cannot be commercially factored (or incentivized) without corresponding metering. In this paper, the co-incidence of generation and consumption in a micro-grid setting is examined over different timeframes using a software based simulation, and the impact of different time intervals for accounting is explored using an algorithmic theoretical approach. It is found that there are predictable trends in the way that metering time periods impact the accuracy of 'peer to peer' accounting. For the limited dataset tested, the inaccuracies were found to be small relative to overall energy consumption, however further work is required to determine whether this can be generalized across the majority of schemes.

1. Introduction

The electricity industry has seen significant cost-reductions in distributed energy resources (ie. rooftop photovoltaics (PV), battery storage, flexible loads) over recent years.

The growing competitiveness of these technologies has seen a range of new energy business models aimed at sharing the apparent reduced transmission and distribution costs where distributed generation is consumed close to the point of production. These businesses and their associated models can be referred to as 'local solar' or 'peer to peer' schemes (Giotitsas, Pazaitis, & Kostakis, 2015) (Rifkin, 2011).

These new players have proposed a range of business models and tariff structures, but the general premise appears similar; a local energy tariff with value between the existing solar feed-in-tariff (FiT) and standard retail consumption tariff is charged to the consumer and passed on to the generator if energy can be shown to have been generated and consumed 'locally' within a given subnetwork or isolated region.

ie. Feed-In-Tariff < 'Local Energy Tariff' < Retail Tariff

This tariff model may be made more financially feasible if distribution and transmission network service provider (DNSP & TNSP) businesses are willing to negotiate reduced rates for 'locally' consumed energy. This would require that DERs generate at peak network times, thus reducing additional investment in network infrastructure. Such an arrangement could be made under a bilateral arrangement or a regulated mechanism such as the proposed Local Generation Network Credits scheme that was rejected by the Australian Energy Market Commission (AEMC) in 2016 (AEMC, 2016b). Retailers and prosumers could share in the reduced distribution and transmission use of service (DUOS & TUOS) charges for energy transacted within the network.

There are currently a range of trials across Australia that aim to facilitate matching local generation and consumption. These can be standalone microgrids, grid-connected embedded networks or existing distribution subnetworks with high penetrations of DERs.

A number of business have begun to market related schemes as 'peer to peer' (P2P) energy. Recently in the Australian context, retail entity Powershop have trialed their 'Your Neighbourhood Solar' model (Powershop, 2017) whereby participants elected to pay a premium on top of their existing retail tariffs to subsidise local solar generation. These models have also been offered alongside new technical metering and billing solutions based on blockchain technologies, such as those from LO3 Energy (LO3, 2017), Power Ledger (PowerLedger, 2017) as well as a 'desktop-trial' completed by AGL (AGL, 2017).

While these local energy or peer-to-peer business models appear to have promise there has been little academic exploration of potential accounting schemes for the 'netting' of generation and consumption within either a physical or virtual embedded network. There appear to be a number of issues that may present barriers or inaccuracies in accounting for energy flows and recording which participants should be entitled to the financial benefits of local generation.

This is particularly relevant in the Australian context, where these business initiatives have been used by regulators to justify further deregulation under the rationale of retail innovation, which is expected to erode margins and improve consumer outcomes (AEMC, 2016a). Such an outcome may not be plausible if emerging competitive structures introduce inappropriate price signals that do not enhance the overall economic efficiency of the electricity network.

The electricity sector is required to precisely match supply and demand at all times and locations across the interconnected network. The question of how commercial arrangements facilitate or perhaps detract from this ongoing supply-demand balancing at a local level provides the motivation for this paper. In particular, we consider some quite specific accounting problems that have emerged in economic modelling of 'peer to peer' energy networks, specifically around the coincident timing of distributed generation and consumption and hence contribution towards this ongoing balancing challenge.

2. Problem Formulation

The underlying value proposition of local or peer to peer energy is that participants are rewarded for aligning consumption with local generation in order to reduce overall industry costs associated with energy service delivery to consumers. Participants are assumed to be operating load and generation nodes in in an embedded network, with an effective 'gate meter' (virtual or physical) that is able in some manner to track the net electricity generation or consumption of all participants in the system. In the ideal case, allocation and payment rules should provide incentives for participants to align consumption and generation and thus reduce reliance on the broader electricity industry's generation and relevant transmission and distribution network.

Such a scheme requires an interval meter connected to every generation and consumption node. In Australia, almost all metering for commercial purposes records average energy flows over 30 minute intervals. In reality of course, fluctuations in PV generation and load profiles can take place on significantly shorter timescales, and this can have economic impacts given that supply-demand balance must be maintained over much faster (seconds) timeframes. For business models looking to facilitate local balancing, this 30 minute metering interval may well mean that in some cases, participants with non-coincident generation and consumption may be allocated payments intended to reward coincidence. This outcome may well have associated broader economic inefficiencies .

In particular, it appears to have been assumed in many 'peer to peer' energy schemes that the aggregate network impact of each participant will be recorded as the same whether meters are logging data on 5-second, 30-second, 5 minute, 30 minute etc. time intervals. This is not the case. Locally generated energy from one subperiod (ie. the first 5 minutes of a 30 minute metering period) may be counted towards somebody's load in subsequent (5 minute) intervals. In some instances a gate meter reading can provide an indication of the discrepancy, but in networks with more than two participants it can be shown that the information loss does not allow the correct accounting strategy to be resolved. These types of issues are not only associated with distributed generation. The wholesale National Electricity Market uses a hybrid 5-30 minute arrangement where dispatch occurs at 5 minute periods while the commercial 'price' is the average of six consecutive 5 minute wholesale prices. The potential economic efficiencies of this have been noted, and there is a rule change for true 5 minute pricing (AEMC, 2017). The national electricity market (NEM) also has a range of ancillary markets that establish commercial signals for large participants for supply-demand balancing over periods of less than 5 minutes. There has however been virtually no discussion of these potential issues for local supply-demand balancing – a gap that this paper aims to address. In particular, we seek to answer two questions:

- What types of inaccuracies are possible due to meter timing inaccuracies as described?
- What metering time period is required in real life for accounting of PV to be near-correct?

The answers to these questions appear to require the comparison of what is recorded to have happened on some nominally small time-scale, versus what seems to have happened on the metering timescale.

Load and PV generation profiles can be volatile, with weather and electrical interference contributing to large fluctuations in energy consumption and export. Figure 1 below shows an example of hypothetical solar and load coincidence between two separate participants in a local solar or 'peer to peer' scheme, over a 30 minute period. An export meter on the PV system participant would record the area under the 'solar' PV curve as generation and an import meter on the participating load would record the area under the load curve as consumption. A 'local solar' sharing or 'peer to peer' scheme would then, typically, net the recorded generation and consumption, and allocate discounted tariffs to reward the coincidence. The true 'peer to peer' generation and consumption of energy however occurs for only a short period (represented by the shaded area under both curves). This means that a scheme operating on a longer metering time scale such as, in this case, 30 minutes would in this case significantly misrepresent the proportion of energy consumed locally.

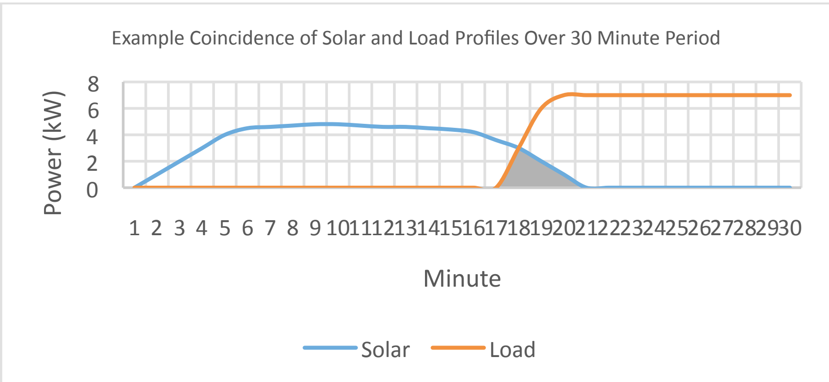


Figure 1. Example Coincidence of Solar and Load Profiles Over 1 to 30 Minutes.

In a network featuring one generator and one consumer such as this, a gate meter can be used to resolve the discrepancy by calculating the total import and export in the system. With three or more participants however, there is not enough information to resolve the true amount of locally consumed energy for each consumer. It can be shown that the ability to accurately resolve the amount of locally consumed energy reduces with each additional participant added to the system.

In the worst case, this might mean that no consumption is coincident with generation, despite all meters appearing to suggest that energy was consumed locally.

2.1. Gate Metering and Total Energy

If a gate meter is present, local energy consumption can be calculated by taking the difference between the gate meter import reading and the sum of all individual readings. Alternatively it can be calculated by taking the difference between the gate meter export reading and the sum of all generation readings. It should be noted that some systems will not be operating with gate meters, for example Powershop's offering, which is intended to operate on existing distribution networks (Powershop, 2017).

'Total Consumed Peer to Peer Energy' by all scheme participants in any given time period t is thus given by:

$$Ep2p\_total\_t = (1k{=}nEk\_t) - Egate\_import\_t \qquad (1)$$

for K consumption participants, with each participant k's energy import given by Ek and gate-metered imported energy as $Egate\_import$

or 'Total Generated Peer to Peer Energy' in any given time period given by

$$Gp2p\_total = (1k{=}nGk) - Ggate\_export \qquad (2)$$

for n generation participants, with each participant k's energy export given by Gk and gate-metered exported energy as $Ggate\_import$

Note that these are equivalent and $Gp2p\_total$ should be equal to $Ep2p\_total$

With the ability to calculate the amount of energy consumed locally within a subnetwork or embedded microgrid, an allocation rule can be defined that will determine each participant's accounting of and payment for coincident generation and consumption.

2.2. Models for 'Fair' Allocation of Renewable Energy Externalities

Price signals are the key economic lever by which operational and investment decisions can be influenced by system designers or policy makers. For uncontrolled loads and DERs (ie. Rooftop PV) the aforementioned issues are accounting-only, in that regardless of local trading arrangements, the rest of the electricity network will be exposed to the same import or export from the system participants. In the case of controlled loads and DERs (ie. battery systems), local energy allocation rules could feasibly impact operational decision-making, and it is important that these structures are modelled in such a way that dominant strategies maximise (or balance) social benefit across the pool of participants and the electricity network more broadly. For both controllable and non-controllable loads and generation sources, local energy allocation rules may impact investment decision-making.

It should also be noted that the concept of economic efficiency or maximisation of net social benefit may differ between the interests of the participants or the network more broadly. Improving economic efficiency may not necessarily be aligned with maximising local consumption, as there may be times in which the most economically efficient outcome may be to assist the rest of the industry, rather than simply do no harm.

It is worth exploring the ways in which energy flows may be accounted for, or allocated, within a 'peer to peer' subnetwork. The economically 'fair' thing to do seems to be to distribute the 'local' tariff among those who participated in local energy consumption and generation (as a charge and payment respectively). However, noting the above points it is clear that the concept of economic fairness needs more detailed consideration.

As electricity flow is difficult to trace back to a generation source, it is not currently practical to determine where locally generated energy has flowed within a network. We are thus presented with the challenge of distributing potentially scarce benefits of local generation (ie. the local tariff) among an arbitrary number of consumers and generators.

There does not yet exist a standard model for allocating locally generated energy in a subnetwork. In determining a rational model it is prudent to assess the model's effectiveness at dealing with sub-standard meter timing issues.

There appear to be two basic solutions to this problem with a number of algorithmic modifications possible.

The simplest solution, (the 'fractional allocation rule') involves calculating the fraction of all consumed energy that came from local generation sources. Each consumer is thus allocated this proportion of their overall timeperiod consumption as having come from local generation sources. While this option is mathematically simple, the dominant strategy for controlled loads in grids with non-dispatchable local generation then appears to be to simultaneously consume at times of solar generation, regardless of the behavior of other participants, as the higher their output the greater the volume of energy consumed will be accounted for as locally generated. In this scenario, loads are able to reduce the volume of local energy allocated to other participants by dispatching at times of high PV output. This may have some advantages in terms of maximising local consumption, but the lack of a mechanism to signal that generation and consumption have been matched may lead to excess consumption.

An alternative solution (the 'quota allocation rule') is to allocate each consumer a fixed quota, a proportion of the total local generation pool for a given time period. If a consumer's consumption is less than their quota, the surplus is added to the pool and remaining consumers' quotas are recalculated. It is feasible that some financial incentive could be introduced to incentivize consumers to stick to their allocated quotas.

2.3. Mathematical Formulation of Fractional Allocation Rule

We recall that in this allocation rule, the total fraction of locally consumed energy is calculated with respect to total consumed energy in a given time period.

This 'peer to peer fraction' for an arbitrary time period is given (with reference to (1)) by:

$$Ep2pfraction = Ep2p\_total Etotal$$

where total 'peer to peer' energy used is given by $Ep2p$ and total consumed energy by $Etotal$.

Each participant is then allocated this fraction of their import as 'peer to peer.' Ie. for participants k in the set of consumption participants $P\,(k0,k1,k2\ldots kn)$:

$$Ep2pk = Ep2pfraction\ Etotalk$$

Similarly, generators are considered to have generated the product of their output and the fraction of p2p energy in the total generation pool (with reference to (2)):

$Gp2pfraction=Gp2p\_totalGtotal$

where $Gtotal$ is the sum of all generator output in the time period.

Each generator k in the set of generator participants $P\,(k0,k1,k2\ldots kn)$ is then allocated this fraction of their export as 'peer to peer' ie.

$Gp2pk=Gp2pfraction\ Gtotalk$

2.4. Mathematical Formulation of Quota Allocation Rule

In the quota scenario, the total energy consumed peer to peer is first calculated. Each consumption participant is initially allocated a proportion of this energy. For simplicity these allocations are assumed equal here but equivalent strategies exist for unequal allocations.

This algorithm must be run in multiple steps, but requires only one pass across the set of participants, as long as the participants are ordered by ascending consumption such that surplus allocations are not re-awarded to already-examined participants. The algorithm thus runs in O(n) time.

Setup: Initialisation of the 'Peer to Peer' Energy Pool

Each participant's quota is generated from a 'pool' of 'peer to peer' energy. Let the pool at step 0 be equal to the total available 'peer to peer' energy:

$Pool0=Ep2p$

Setup: Initial 'Peer to Peer' Allocation

Let the 'peer to peer' allocation of the lowest-consumption participant (in a network with *n* total participants) be given by:

$Ep2p\_allocation0=Pool0n$

Step 1: Calculation of a Participant's 'Peer to Peer' Consumption

A participant k's 'peer to peer' energy consumption is then calculated. Their 'peer to peer' consumption must always be less than or equal to their allocation, ie.

$$Ep2pk=\min(Etotalk,Ep\ 2pallocationk)$$

Step 2: Update of Pool

To calculate the next participant's allocation, any surplus from the previous participant is left in the pool and this is divided by the number of remaining unexamined participants.

$Poolk+1=Poolk-Ep2pk$

Step 3: Update of Next Participant's 'Peer to Peer' Allocation

The 'peer to peer' allocation for the next participant is then recalculated:

$$E_{p2p\_allocation}^{k+1} = \frac{Pool^{k+1}}{n-(k+1)}$$

Loop

Steps 1, 2 and 3 are repeated until all participants have been allocated excess peer to peer energy.

It is implicit that an equivalent strategy exists for allocating ‘peer to peer’ generation among generators. If not all generated energy in the system is used by participants, there exists an accounting task in allocating which participants are allowed a higher ‘peer to peer’ pool price or tariff.

We have thus defined a quota-based allocation rule based on the number of participants on the generation and consumption sides.

Potential problems may arise with this quota approach in large loads or generators receiving relatively small allocations but it is unclear whether this is an inefficient signal. There does however appear to be an incentive from a participant entity perspective for participants to break up generation and consumption into smaller metering units so as to received a greater share of the overall allocation. Possible modifications include changing ‘n’ on the generation side to equal units of generation capacity. A similar model on the consumption side may require participants to buy capacity allocations.

3. Determining Impact and Effectiveness of Metering and Allocation Strategies

3.1. A Measure of Comparison for Meter Timing Period Lengths

Now that two standard accounting scenarios have been defined, we can examine whether the overall outcomes are different depending on whether generation and consumption are measured on shorter or longer time intervals.

We define a measure of an individual participant k’s deviation D_k from short to long time periods as the difference in their longer time period peer to peer energy and their cumulative short time period peer to peer energy, where the long time period is a multiple t of the short time period and the measure is normalized to the participant’s total energy consumption in the long time period.

$$D_k = \frac{\left| E_{p2p}^{long} - \sum_{1}^{t} E_{p2p}^{short} \right|}{E_{total}^{long}}$$

In the best case scenario, the accounting result for every participant in the network under a long time period is equal to the cumulative short time period accounts, so the deviation is zero. In the worst case, either of the numerator terms will be zero and thus the remaining term will be equal to the denominator, so the deviation measure will be 1.

3.2. Simulation Method

A software program was built that takes as input a folder of formatted CSV files with time series generation and consumption data recorded on five minute intervals. These data files are used as the basis for the creation of object-oriented software models that can be queried to find consumption and generation at any time period in the series, on any given time scale (ie. 5, 10, 15 minutes).

Participants described by the time series data are assumed to be participating in a peer to peer scheme under two allocation rules: the quota allocation rule and the fractional allocation rule. A python implementation of each rule was developed based on the algorithms outlined previously. The algorithms were programmed record the assigned 'peer to peer' energy consumed or generated by each participant under their respective allocation rule.

The results of each allocation algorithm were then processed to calculate the deviation score Dk for each participant in the respective sets of consumers and generators. These scores were then averaged across all time periods where they could be calculated (ie. when a participant had non-zero generation or consumption).

In order to avoid biasing the results toward outlier energy fluctuations in the dataset, this simulation was then re-run multiple times, moving the starting time forward by one interval of the shortest period (ie. 5 minutes). The results of these multiple simulations are then averaged for each participant.

3.3. Data Sources & Simulation

The simulation was used to model the impacts of meter timing changes on a hypothetical 'peer to peer' network comprising 20 solar and load systems located close to the University of New South Wales in Sydney, Australia. The sites were chosen for their proximity and the availability of 5-minute generation and consumption data. The datasets were sourced from pvoutput.org and correctly formatted versions can be found for review in the code repository.

The simulation was run across ten days of publicly available data. Where gaps existed in the datasets, the corresponding participant model returned zero kWh consumption or generation for those time periods. The consumption and generation data is shown below in figure 2. It can be seen that there is some volatility in the load data, but that for these periods the solar data less volatile. This will impact the results by reducing the metering error, as in any given time period a high Dkvalue is dependent on a change in both generation and consumption.

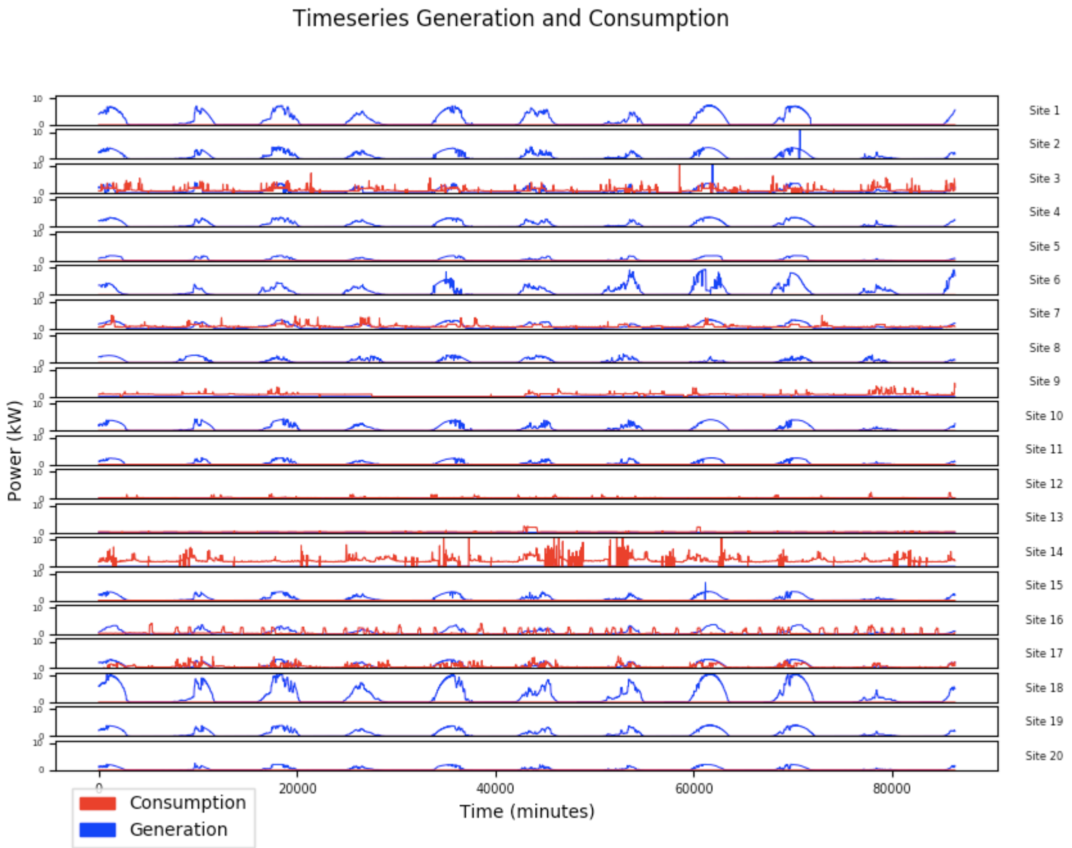
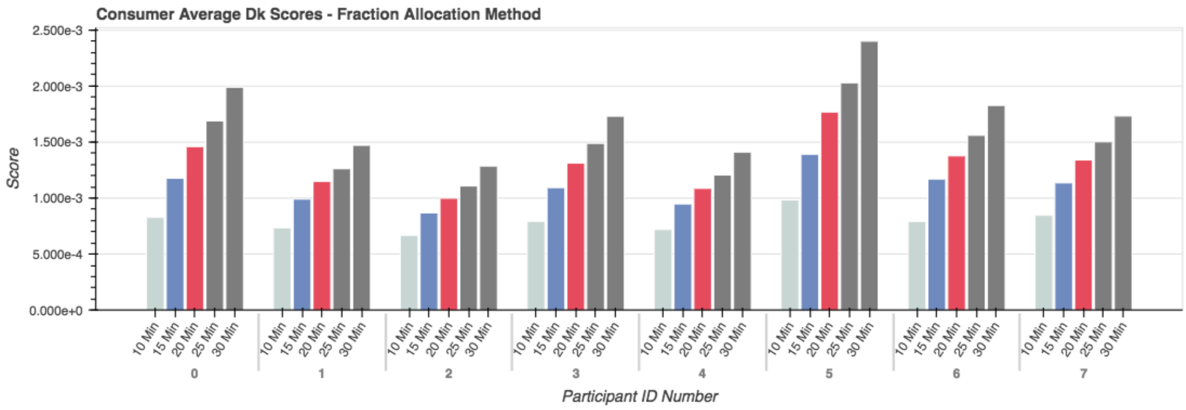


Figure 2. Time Series Generation and Consumption at Measured Sites for a Sample 10 Day Period.

3.4. Results

In section 2.3, a relationship in the fractional allocation rule was derived between the time period multiple and the deviation score Dk, whereby Dk could be said to be increasing less with each subsequent time period multiple. The results of the 'peer to peer' network simulation do not contradict this relationship, with the general trend available in figure 3 for consumers and figure 4 for generators below. Participants that showed no consumption or generation were omitted from the respective charts for simplicity.



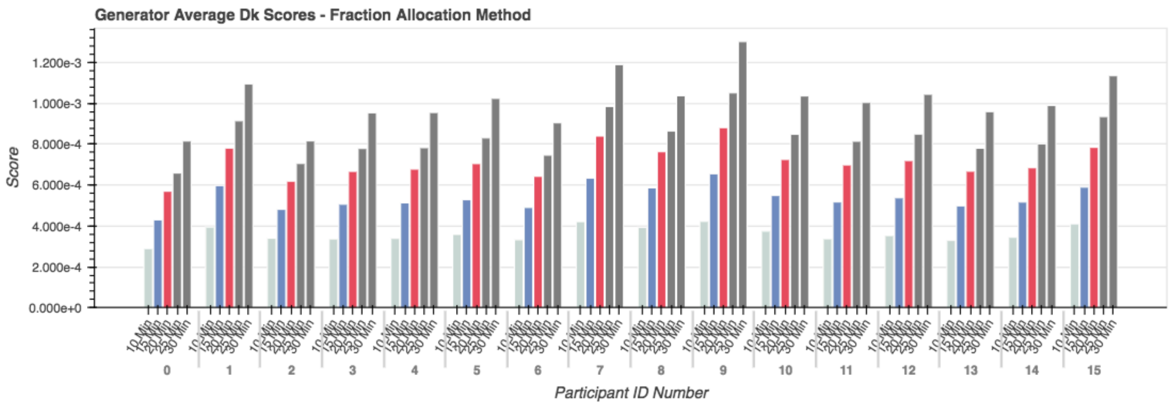


Figure 3. Deviation Scores for Each Generation and Consumption Participant under Fractional Allocation Rule

The results for energy consumers under the quota allocation method appear to show a similar trend in terms of increasing deviation scores $Dk$for each participant k. For generators however there appears to be no clear trend as the time period length is increased; some participants appear to see a reduction in deviation score, while others see an increase. There is however in the case of the generators a much larger deviation than was observed among consumers. The results can be seen in Figure 4 below.

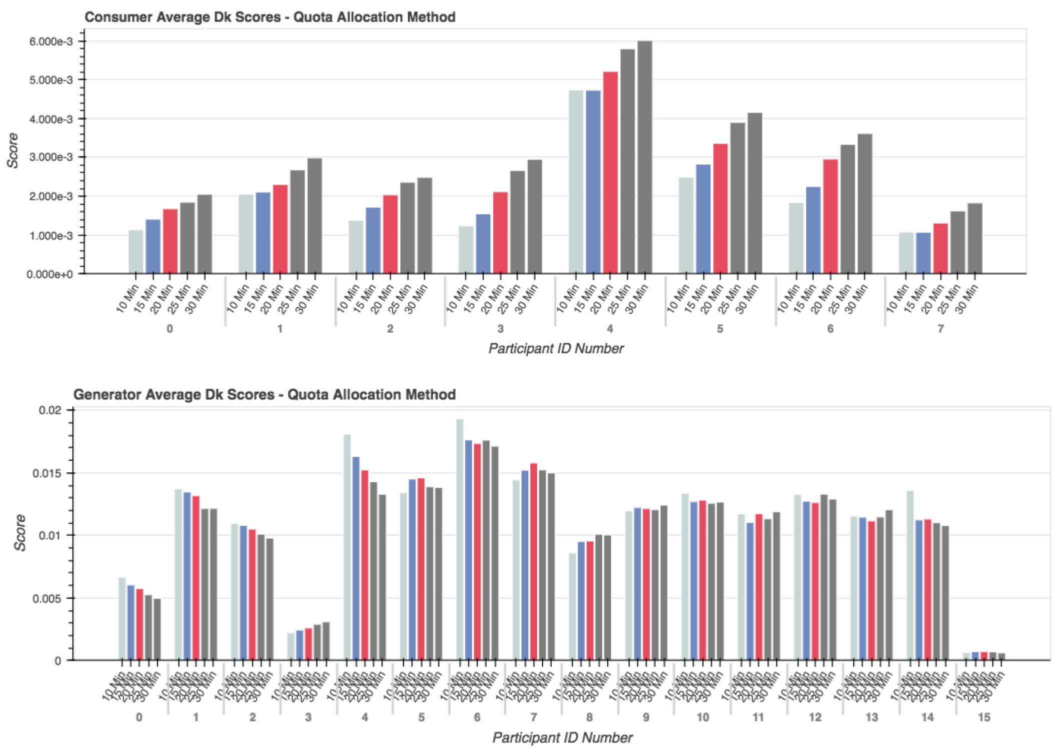


Figure 4. Deviation Scores for Each Generation and Consumption Participant under Fractional Allocation Rule

3.5. Discussion

It appears that the fractional allocation rule provides predictable results with regard to the deviation in allocation accuracy as time period length is increased. The accuracy of the quota allocation rule for each participant appears to be more dependent on other factors (eg. generation / consumption profile or the number of participants).

The results do not appear to contradict the expected trends in metering accuracy as time period length is increased, however the expected reduction in the impact of increased time period on fractional allocation rule deviation was not directly observed.

The results of this analysis should be taken as a 'first pass' at quantifying the impacts of meter timing in peer to peer energy trading schemes. There appear to be several steps that could be taken to extend this analysis. The data series length appears to be a potential limitation, as the measurement period may not have coincided with potentially volatile days (ie. cloudy skies for PV / irregular load use). As the research is intended to measure the impact of volatile load and PV output on meter timing, this is a significant limitation.

Additionally, the assumption in this simulation was that 5 minutes was a 'rational resolution' as defined in section 2.2. This assumption may not hold true, and further analysis of higher-frequency measurements (ie. 30 seconds or 5 seconds) is needed to reveal the true 'rational resolution' for 'peer to peer' energy trading analysis. This further highlights the growing research need for publicly available high-resolution PV output and load data.

4. Conclusion

The rapidly falling capital cost of DERs and associated 'smart' metering technologies appears to be empowering a range of new business structures, based on the 'netting' of consumption and generation between different participants in an electricity network. These 'peer to peer' energy sharing or trading schemes rely on the assumption of coincidence between generation and consumption. Many feature incentive mechanisms that appear designed to encourage coincident generation and consumption.

These schemes are however reliant on metering that provides data on time scales that can account for expected variations between generation and consumption. If metering does not provide the appropriate time resolution, accounting errors will be introduced in participant settlements, and incentive structures will perform in an unexpected or inefficient manner, thus negating the perceived advantages of a 'peer to peer' network.

This paper explored a range of allocation rule designs intended to account for energy flows in a 'peer to peer' system. Two basic rule structures are developed, based on fractional accounting and quota-based accounting respectively. These structures are intended as a basis upon which tariff structures and incentives can be built to incentivise efficient behaviour in a 'peer to peer' network.

A definition of deviation from expected or 'near-correct' accounting was then developed, based on the properties of the two rules. An open-source simulation was then developed in python which aimed to apply the allocation rule algorithms and measures of meter timing deviation to real-world datasets. The simulation was run on ten days of solar and load data comprising a hypothetical 'peer to peer' energy sharing network. The results of this analysis did not appear to contradict the theoretical explorations of meter timing impacts upon accounting accuracy, though further investigation on larger datasets with shorter time resolutions is required to fully explore the potential implications of each rule and the meter timing requirements for accurate energy flow accounting.

5. References

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Acknowledgements

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