# *capacity subscription mechanism FOR COMMUNITY MICROGRIDS*

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#### **Overview**

Even though modern technologies easily allow the universal access of electricity and grid services, economic considerations have limited the availability of grid connection in remote, sparsely-populated or underdeveloped regions. Inequity associated with difference in economies of scale in densely populated vs. sparsely populated regions, metropolitan vs. remote regions calls for localised distributed grid in both developing and developed economies. As a new generation of energy infrastructure, community microgrids, are likely to help reduce energy poverty, bridge the gap between regional inequity in electricity supply, and provide more stable, cleaner and cheaper supply to the local communities.

We have defined community microgrids as ‘*a self-contained and self-sufficient local electricity supply system, either standalone or connected to a centralised grid of regional or national scale, comprising residential and other electric loads, and can be supported by high penetrations of local distributed renewables, other distributed energy and demand-side resources*’ (Gui et al. 2016). Community microgrids can not only deliver enormous social, economic and environmental benefits to communities, such as provision of affordable and competitive electricity supply, but also allow the participation and injection of private capitals, which help to alleviate the pressure and requirements for government subsidies to reduce energy poverty and inequity.

In a community microgrid, the ultimate goal is to achieve the maximum ex ante social welfare subject to the constraint that the fixed costs to be recovered. A capacity subscription mechanism (Doorman 2005) is intuitively attractive for community microgrids for a number of reasons: a) willingness to pay for capacity reﬂects benefits that customers value and customers’ preference for their own consumption; consumers with higher flexibility in reducing consumption will obtain a small amount of capacity, resulting in considerable curtailment when there is a capacity shortage. On the other hand, consumers with a low flexibility in reducing their consumption will obtain more capacity for higher level of security of supply; b) quality of supply becomes a private good instead of a public good, and demand and supply can be matched in an optimal way; c) introduction of demand for capacity enables the incorporation of market concepts, without the operational burden of a competitive spot market. This allows the customer demand to reﬂect the real function of capacity, which is particularly important in an environment of high share of intemittent renewable generation.

#### **Methods**

Research on the capacity sizing and planning for community microgrids has mostly centred around optimising the generation mix given expected demand profile, and limited work has explored customer preferences as part of the pricing strategy in post investment decisions (Vatanparvar and Al Faruque 2015). Drawing insights and experience from consumer subscription services in electricity markets to foster price-responsive demand proposed by a number of researchers (Chao 2012), we attempt to develop a capacity subscription mechanism for community microgrids to provide incentives and tools for maximising social welfare incorporating customers preferences and attracting investments.

The proposed customer subscription mechanism entails a two-stage decision-making at different time horizon. At the capacity investment planning stage, each customer will choose specific levels of capacity subscription based on their consumption profile and preferences, which also provides insights to the capacity planner and investors on how much capacities should be procured and curtailment options. At the time of consumption, customers can adjust their consumption level based on the real-time energy prices determined by the level of supply and demand. The differences between the subscribed capacity and the actual consumption are settled at the energy price at the time reflecting market conditions, including the foregone consumption, i.e. the differences below the customer‘s subscribed consumption, that may either meet additional demand in the system or replenish the future supply (for example recharging the battery storage). The optimal investment level is to ﬁnd the optimal usage price *z* ($/kWh), capacity prices *k* ($/kW), and the optimal installed capacity *X*(kW) that would be the most efficient when yielding zero long-term profits in the microgrid.

**Results**

Capacity subscription in a community microgrid works as follows: each customer subscribes to a particular level of capacity *An* in advance based on their consumption preferences. The customer pays a capacity charge *k* for the amount he subscribes to. The customer then chooses the ex post demand schedule*q* after the energy price *z* is revealed, where *z* denotes the state-dependent electricity prices. If the energy price *z* is lower than the subscribed capacity price *k*, the subscribed capacity will be delivered and we assign *ξ*=1. The difference between the actual consumption level *q* and the subscribed capacity *An* will be settled at the price z for a net payment of *z(q- An)*. If the price *z* is higher than the subscribed price *k*, the service will be curtailed to the subscribed amount and we assign *ξ*=0. The customer will need to procure the actual consumption *q* at the energy price *z*, for a net payment of *zq-kAn*. This implies that the foregone consumption below the subscribed capacity is also paid at the energy price *z* for providing either demand relief in the system or supply for replenishing the supply (for example recharging the battery storage).

## Customer preferences and customer surplus

Let *u(z,q,h,ω)* be the marginal willingness-to-pay of consumer *h* with a desired variable demand profile *rh*. We assume that u is decreasing in *q* but is increasing in *h*. A customer’s decision process involves to solve the ex post surplus maximization problem and the decision can be formulated as,

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The aggregate ex post demand for electricity is . Given the energy price *z*, the aggreate customer suplus, that equals to the agregate individual customer utility function, is thus written as

*Producer surplus and Social welfare function*

We consider a unit capacity cost of *β* and varying operating cost at *c*. Let *Xi* denotes the installed capacity of technology *i*, the random function *Yi* (*Xi, ω)* denotes the available capacity, whose realization is known to the producer. The producers’ expected surplus equals the expected short-run profit minus the capacity investment costs:

According to the welfare economics, the social welfare function can be defined as the sum of consumers’ and producers’ surplus, which can be written as

when the price is determined by the market supply and demand equilibrium condition .

*Long-term investments incentives*

If there is excess available capacity in the system, the energy price *z* is most likely to be lower than the capacity price *k*, the customers will benefit little to buy any capacity at any *k* greater than 0. However, when the capacity is limited and supply shortage occurs, the energy price *z* will exceed the capacity price *k*, which will provide incentives for customers to buy capacity at the price *k* in advance. The customer that chooses not to subscribe any capacity beforehand will be fully exposed in the spot market and potentially pay high spot price during the supply shortage. Thus, the capacity subscription mechanism itself encourages the optimal capacity investments from the producer or the planner in order to attract a sufficient amount of subscription capacities upfront for predictable revenue streams to avoid ‘missing money problem‘; at the same time, the customers are offered with options and flexibility to select their preferred consumption profile within their budget.

#### **Conclusions**

A framework of capacity subscription mechanism with self-rationing is proposed to address major problems around community microgrid capacity planning. The mechanism provides an efficient solution to maximise the social welfare, i.e. the customer surplus and the producer surplus, to assist in determining the optimal pricing and capacity investment decisions. Its central feature is a centrally planned and controlled operation to pre-subscribe the demand level to determine the level of generation investment based on customer preferences. Practical case studies will need to be investigated to further demonstrate how the capacity subscription mechanism should be designed and operated to meet social and economic goals of community microgrids.

**References**

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