PEAK DEMAND CHARGE REDUCTION IN MICROGRIDS THROUGH ADAPTIVE OPTIMAL ENERGY MANAGEMENT

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ABSTRACT

This paper analyzes demand charge reduction potential in microgrids. It first categorizes different tariff and demand charge programs from the perspective of utility and consumer. It then gives analysis of how the consumer load type and profile has different potential for different demand charge programs. A descriptive evaluation of different decentralized energy sources in mitigating the peak demand is given. Finally, peak mitigation through microgrid optimal energy management and economic dispatch is presented where the benefit of having multi-generation microgrid provides superior solution in comparison to simple solutions which are based on PV and battery only.

INTRODUCTION

Demand charges are standard part of billing structure for commercial and industrial consumers across the world. While some utilities see demand charges as a standard way of covering the electricity production costs such as fuel, other see it also as a way to regulate the peak demand in their networks. Demand charges are reaching to over 50$/kW in some parts of US [] and can amount to more than 70% of electricity bill in Ontario Canada, so the reduction of those becomes a necessity and at such high value presents huge savings potential. In recent years, these types of consumers have been more or less successfully trying to reduce demand charges with different behind the meter solutions. As a rule those solutions are based on a single technology, either conventional Gensets (Diesel or Gas), CHP, PV or BESS solutions. At the same time however, the challenge of demand charge reduction has only grown in complexity as well as solution potential.

The number of tariff models available to the consumer has increased and the dynamics at which those tariffs change has also increased. Grid Codes are introducing constraints on different technologies, for example minimal usage efficiency of CHP units or back feed limits and ramping constraints of the injected PV power. At the same time, local and country wide governing entities are introducing different subsidy programs which make business cases for some of the distributed energy resources more viable. All of these factors make demand charge reduction more complex and harder to implement, especially because any investment requires a long term stability to fulfill the initial business case.

Carefully designed and optimally run, Microgrids offer a most comprehensive and robust solution for demand charge reduction. They are able to optimize a number of different distributed generation sources as well as controllable loads and at the same time cover all of the constraints.

This work first evaluates different demand charge types with respect to the tariff model and overall price of energy. This work also evaluates the capacity of different distributed generation sources (conventional gensets, CHP, PV and BESS) in mitigating peak demand and reducing the demand charges, with the consideration of above mentioned constraints. Finally, we present adaptive optimal energy management solution for microgrids which is able, based on the demand charge schedule/forecast to optimally dispatch all available microgrid assets to maximize demand charge reduction. An example of Ontario Global Adjustment program, as one of the most aggressive demand charge tariffs worldwide is used to show a business case for a PV, CHP and BESS driven microgrid.

It is very important for utilities which design demand charge tariffs to understand not only the relationship between the system wide peak and demand charges which they would like their customers to mitigate but also the capability of the customer to do this. In order for the customer to implement reduction methods he needs to have a clear cost saving plan

TARIFFS AND DEMAND CHARGE

In order to understand the demand charge a tariff structure has to be defined and broken down in such way which enables a definition of a general model. This can be simply done by categorizing the tariff structure elements by the unit of dependency variable. Utilities mostly model their tariff structure as a reflection to the structure of production costs. This is why a number of tariffs include different types of charges which the consumer may have no direct connection to.

One of the key issues with demand charge programs is that unfortunately most utilities around the world still do not commit under contract or otherwise to keep one tariff program unchanged during a longer period of time. Any demand peak mitigation action on the consumer side requires significant investments which have to be justified by a solid business case. All business cases are based on several years or internal rate of return IRR calculation. This is why microgrid solutions with a multi-generation asset portfolio have greatest resilience towards changing tariffs.

Tariff part	Unit of dependency variable
Energy charges, Fuel Charges, Transport charges, Renewable charges, Solar-Hydro surcharge	Per kWh consumed
Demand charges, State charges	Per kWp and in steps
Service charges, Interconnection charges	Fixed in currency
Taxes	% of Total Brutto bill price
Reactive Power charge Leading and Lagging	Per excess kVAr
Subsidy programs	various

Table 1 – Categorized tariff structure

DEMAND CHARGE TYPES

Demand peak types determine the effort and technology needed on the consumer's side. It mostly determines the type of forecast needed in order to mitigate the peaks. The There are two types of demand peaks:

Coincident peaks

Coincident peaks represent the maximum demand power consumed by the customer during the specific periods of time which are defined by the utility and which as a rule coincide to the system-wide peak demand. Within this category there is a very important sub-categorization:

Scheduled coincident peaks happen in predefined and known time frame and have schedule which even if dynamic, is known to the end customer in advance. It may be matching the time of use (TOU) tariff or not, but the end consumer has clear knowledge of this time frame and hence has better chance of reducing his own peak during this period. Utility takes the responsibility here to accurately forecast the system-wide peak and if demand schedule is dynamic produce and deliver the peak schedule to the consumer.

Adjusted coincident peaks are not scheduled and have no known or no fixed time frame because the utility also does not know when exactly the system wide peak will occur. Hence those peak periods are exactly defined only after the billing or season period is passed and then the consumer's bill price is adjusted or the new price defined for the future period. This means that it is left to the consumer to obtain and take own responsibility in forecasting the system-wide peak. This is obviously a very demanding and complex action so there are normally special third party services which provide this forecast at a cost.

Non-coincident peaks

Non-coincident peaks represent the consumer's maximum demand during the billing period which is most often measured as average maximum peak demand over 15 minutes. For this type of peak demand, the consumer is responsible to forecast and mitigate own peak only independent of the system-wide peak. Non-coincident peak programs are designed to support the utility reserve planning in which the consumer is contracted a limited peak value with reasonable price, but if that one is violated high penalties may be incurred.

LOAD PROFILE DEPENDENCY

Microgrids mostly include following consumer types which also determine their Load profile:

1. Campuses
2. Islands
3. Critical infrastructures
4. Commercial and Industry

An extensive study is done for industrial load types for demand response [2]. Load profile of the consumer is a determining factor for ability to mitigate the peak demand. This means that in order to be able to determine the peak demand reduction potential the consumer must have a measured historical Load data over entire year with the sampling time matching that of a utility. With the consideration of the capacity of different technologies to provide peak-shaving or energy shifting service it is clear that daily profile is considered, i.e. within 24h time frames with 15 minute steps. We define a factor which measures the potential for reducing the peak as the ratio between the peak power and energy consumption during one day:

$$F^{n}_{DCR} = n \;/ \sum_{t=1}^{n=96} \frac{P_{peak}}{P_t}$$

We use this factor to determine how "peaky" the load profile is and higher the factor $\boldsymbol{F_{DCR}}$ the greater the potential for peak demand reduction.

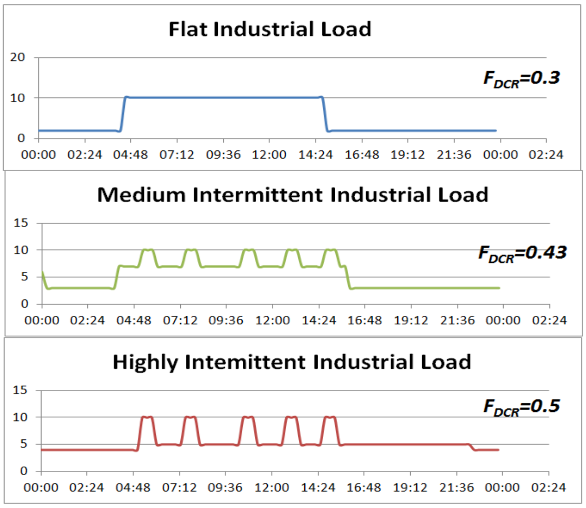

Figure 1. Industrial load profiles with different $\boldsymbol{F_{DCR}}$

In an example on Figure 1. 3 Load profiles with same energy consumption in one day are shown but with very different potential for peak demand reduction.

DECENTRALIZED ENERGY SOURCES

There are a number of different technologies which have capacity for demand peak mitigation and they all have strengths and weaknesses. In microgrids we are able to assemble an optimal generation mix of different generation assets which can provide demand charge reduction even in tariff changing conditions as shown on Figure 2.

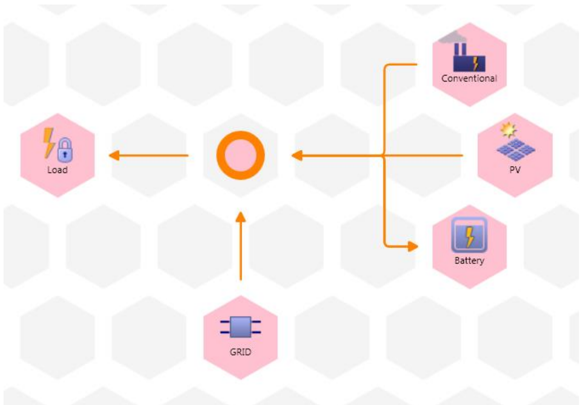

Figure 2. Microgrid model for demand charge reduction

There are several key factors which determine the success of the reduction:

1. Good Load and generation forecasting
2. Choosing optimal mix of DER
3. Optimal sizing of the DER
4. Optimal energy management

We further analyse the decentralized assets and their ability to reduce demand peak.

Deferrable Load

Load itself or some part of it can be a controllable asset and in that respect can be used to mitigate the peak. Commercial and industrial customers may likely be able to deffer part of their loads while those of critical infrastructures may not. While it is unlikely that any consumer would shut down machines or assets which are needed for their business running, most of the above mentioned consumer types have parts of the load such as air conditioning/heating which may be significant deferrable load. By properly planning and controlling tha air-conditioning especially for coincident demand programs significant reduction can be achieved. In order to completely preserve the continuity of AC running, thermal storage may be used.

Photovoltaic

PV installations have a capacity to reduce overall consumption, but to reduce the peak demand has obvious limitation of weather uncertainty. Independent of the demand charge type PV is generally not reliable for peak mitigation unless it is complemented with a battery storage system which would then be able to compensate for the weather uncertainty. In case of aggressive demand charge tariffs there may be a feasible business case with oversized PV where even curtailing energy brings overall benefit.

Conventional generators

Gas and Diesel generators with or without CHP have the advantage over the renewable sources and storage systems that their power production is available at all times as well as over longer periods of time which makes them perfect choice for flat load profiles. They may however have limitation in response time as well as emissions and efficiency constraints which are sometimes imposed by the state or grid code. In case of CHPs there is a limitation in the thermal power limits. If CHP is producing too much thermal power and demand charge reduction requires that it delivers maximum electrical power it may be necessary to dissipate the excessive heat through the ventilation.

Battery Energy Storage System - BESS

Battery storage is ideal resource for mitigating relatively short peaks and to complement renewable resources where energy could be stored at low peak times to be delivered at high peak times. However for longer and continuous peak periods BESS lacks the capacity. BESS capacity increase directly increases CAPEX so it is of great importance to properly size the BESS as well as to plan for charging/discharging cycles in real-time.
BESS utilization relies heavily on accurate forecasting and if this is not fulfilled on one single day when BESS state of charge is not properly planned, it annihilates the demand charge reduction of the whole billing period. This is again why having a microgrid with multi-generation mix including BESS has greater resilience in peak reduction.

OPTIMAL ENERGY MANAGEMENT

In a microgrid with a multiple distributed energy sources demand charge reduction is achieved with optimal energy management. As shown on Figure X in the first step weather data is obtained by the weather service based on which Load forecast and renewable Generation forecast is generated. Those are done mostly 24h ahead, sometimes also intraday. In case of coincidental peak demand reduction model demand forecast service is interfaced to receive the updated tariff values. These data are then used to perform economic dispatch optimization which produces unit commitment plan/schedule for every single microgrid asset. This plan is then executed in real-time. As the initial schedule is based on the forecasts and in real-time it deviates from that forecast real-time optimization is still needed to calculate the necessary adapted unit commitment. This is done on a sub-minute time step basis and executed down on the generators through set-points. This is presented on Figure 3.

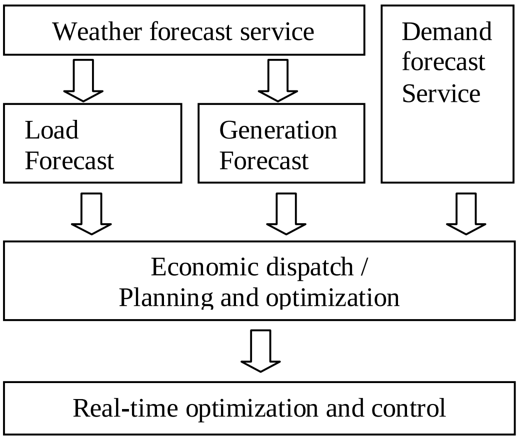

Figure 3. Optimal energy management solution

Demand charge reduction in a microgrid with a multi-generation distributed energy sources is an optimization problem. In [4] Demand charge reduction algorithms for microgrids are analyzed and compared. Although it is executed and constrained by technical variables it is an economical or cost based optimization problem. All assets are modelled with their technical

$$C_E = \sum_{t=1}^{t=96} \left[\left(C_{PV}^t P_{PV}^t \right) + C_{ESS}^t \left(|P_{ESS}^{+t}| + |P_{ESS}^{-t}| \right) + \left(C_g^t P_g^t \right) \right]$$

P_g^t - power produced by PV
P_{ESS}^{+t} - power produced by BESS when discharging
P_{ESS}^{+t} - power consumed by BESS when charging
P_g^t - power generated by conventional generators

Subject to following constraints:

- Unit capacity limits: the output of each unit must be within its minimum and maximum limits
- Ramp rates: output of each unit cannot change more than allowed by the ramp rate
- BESS state of charge within the limits
- Equality constraint: The total power output must match the load for each time interval
- Overproduction of renewables is curtailed to avoid the no solution problem

ESS SOC limits: For each time interval the SOC must be with the SOC limits of the ESS
The cost of operating the battery comes from the less than 100% efficiency; i.e. some energy is lost during conversion. Time span of 96 15-minute time steps is considered.

We take the example of Ontario Global Adjustment program [3] which has very radical coincident peak demand charge initiative:

1. Based on the consumer peak load consumption during 5 global system wide peaks in duration of 1h, consumer is calculated a global adjustment factor based on which the demand charge for the whole next year is defined.
2. The Consumer is responsible for obtaining the best possible system wide peak forecast.

Using optimal energy management we simulate two scenarios to mitigate the peak demand based on the forecasted peak which is presented on Figure 4. and 5. In the first scenario only BESS is used and even though optimally sized and engaged at highest forecasted probability of peak occurring it gets depleted before the actual real peak occurs. In the second scenario we use microgird optimal energy dispatch over PV, BESS and CHP and show that much longer period of anticipated peak forecast can be covered hence making sure that the peak is successfully mitigated.

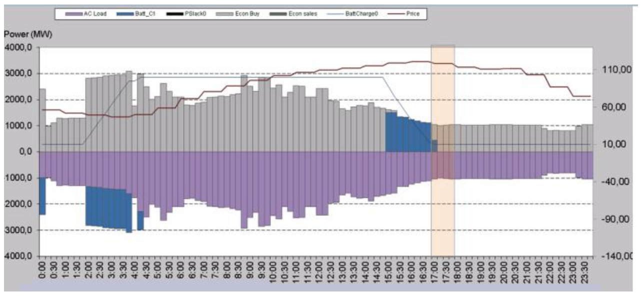

Figure 4. Peak mitigation with BESS only

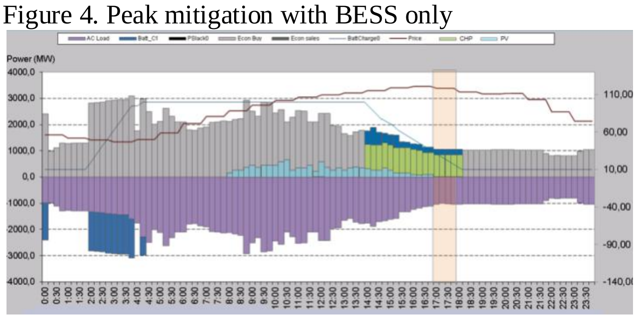

Figure 5. Peak mitigation with PV, CHP and BESS

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