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Market-Based Decision Guidance
Framework for Power and Alternative
Energy Collaboration

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A dissertation submitted in partial fulfillment of the requirements for the degree of
I am also grateful and forever indebted to my country for extending the financial support
3.3 Optimizing Global Benefit
3.3 Units’ $\Delta$ Distribution

3.5 Test Data Showing $\Delta$ Benefit Obtained and Optimization Time

4.4 Added Benefit Distribution

7.1 Typical Day Profile Resolution Time
7.8 Simulation Mean Time - Typical Load Profile vs. Random Load . . . . .
once a static network into a more flexible grid. Microgrids have also been deployed to serve supply and demand have resulted in complex systems where inefficiencies are possible and stored efficiently, therefore, managing such resource requires considerable attention.
dresses different aspect of the electrical power generation and consumption using opti-

More specifically, in real-time, we present and implement a model of how to organize a
guarantees efficient execution and a method for the fair distribution of collaboration gains.

\textit{equal collaboration profitability}

which are formally defined in the dissertation.

to efficiently operate at the specified time intervals with minimal overhead cost.
Previously power consumers are becoming power producers. Houses can be outfitted with such collaboration. More specifically, I propose how to develop such methods for both the
Different Commercial and Industrial (C&I) organizations or units within these organizations may not tolerate shortages or delay in services such as office lighting or computer servers.
Considering all these complexities, it becomes obvious that there is a benefit and a room
different power resources. In real-time interaction, an issue like how to best organize a
the market within different time-frame considerations that are applicable to the nature of
the market is also necessary for the effective operation of the market. Finally, the benefits
efficient fashion to motivate participants to better provide more accurate information that
would not affect their gains from the participation.

ational planning of the use of different resources. To achieve such collaboration, many
questions need to be addressed. For example, an efficient and transparent coalition for-
benefit by joining a coalition, there is a decision of what is the best coalition given the units’
different available resources. Assuming the coalition is determined, there is also the question
of how to optimally plan such that every unit’s benefit is maximized. A primary market

tion. There have been numerous efforts on how to best structure the market to increase
to demand and price changes of getting power, the question of how to distribute the benefit

the impact on a unit of the coalition differ according to its size and order of joining such

the consortium without negatively affecting the benefit of any single organization as a result

the electric power life cycle while not taking into consideration the overall effects of such

running a specific service. Stakeholders are rarely consulted on the actual benefit (or utility) or running a specific service. This process is either considered costly or infeasible especially

abstracted as an overall benefit. Providing this information is vital to the determination of
Furthermore, most existing models aim to either improve efficiency or simply just cut options. This utility power contract typically specifies the rate that the cost of power is to be calculated which usually has two parts. The first part is the cost of total kWh quantity cost of peak demand which, if exceeded, penalty rates apply which could affect the entire short time (e.g., 30 minutes), it could affect the cost per kW over the entire term of the be expensive but at certain times it could be a cost effective choice due to the higher cost of
for different purposes (e.g., reducing peak demand, enhancing reliability, reducing capital

simply means that these loads can be deferred up to a certain extent without much effect

effects of a single decision without a comprehensive framework that enables an organization
generation temporarily until that demand is satisfied. This scenario poses an important
possible that this unit can afford to shut down a service if another unit or department
significant peak demand overage costs or resorting to spot market.

•

of peak demand, and fair distribution of collaboration benefits).
defined properties of quantity required for these services over a specified time horizon. The market resolves guarantees the formally defined properties of benefit distribution fairness.
I also defined four properties that the market resolution must satisfy, namely,

*equal collaboration profitability*

model and prove that it satisfies the desirable market properties.

components formally defines the cost, revenue, intrinsic value, constraints, and control

that the implemented system is feasible to operate efficiently within required time
laboration. The first section present an overview of the deregulated power markets. The characteristics [7]. Most of the work is concerned with different parts of market design, Different approaches to the use of auctions in electric markets has been investigated, e.g., in consumers power procurement optimization by evaluating different procurement options some effort to control peak demand and reduce overall consumption by using physical im-

Furthermore, such concepts have been employed in other fields like computational sys-
Renewable resources are becoming a significant part of the energy for a growing number to be a significant part of energy portfolio.

sources which is that it is difficult to predict their throughput over a long time horizon efforts to deal with reducing power consumption costs either through improving technological efficiency or through market supply and demand mechanisms. An extensive body of are motivated by being promised financial incentives if they comply. Demand response en-
customers of a power company where participants place bids that correspond to benefits
time span compared to flat-rate and other schemes and resulted in the reductions of peak-
and the cascading effects of power components planning for units of an organization or
propose a fair mechanism to sharing the extra benefit of collaboration versus working alone
the problem of finding the most optimal and cost effective operational planning of power
resources (e.g., nuclear, thermal, renewable). While this approach is very effective for the
an overview of a typical microgrid installation. As can be seen in the figure, microgrids

POCC

can afford reduction in power and there also loads that can delayed or rescheduled. Smart
Decision support system can be defined as a computer application that support complex recommendation based on specific optimization models [36–38].
is defined as:

\[ \phi \cup \{\} \]

value also defines a number of axioms and provides proves a proof that these axioms are satisfied. The axioms include:

Efficiency: This axiom simply means that the sum of all players

\[ \phi \]
smaller subcoalitions that maximizes their value. A payoff vector

\[ \forall \subseteq \geq \]

Complete). A value function of an MILP type would make calculating possible payoffs for all
decision optimization, and guarantees the formally defined properties of consumption which help maximize their returns. Short spikes in power consumption affects peak-demand (kW) that an organization reaches during a specific contractual consumption period. This peak-demand constitutes a significant part of the electric consumption cost
of electricity to increase significantly. Therefore, C&I customers are motivated to reduce

comprises of different units (e.g. schools, departments, centers, etc.). These units need

Power) provides power to GMU according to an agreed upon contract which specifies the
terms on which Dominion provides power. More specifically, it states the price per kWh

the services to be shut down is made. Moreover, units benefiting from the services are rarely
organizational added value ($\Delta$) by exchanging the peak peak demand budget, and (2) how to fairly distribute this $\Delta$ among organizational units. More specifically, the contributions

First, we propose and formally define a Peak Load Allocation Market (PLAM) framework. The idea is to divide an organization into units where each unit has a fixed peak up to the specified demand budget. For every power consumption time interval, the unit automatically submits a bid, which indicates the services it needs to run, the benefit value which are defined formally in this next section.

run that maximizes the global organization benefit while ensuring feasibility, i.e., that the

benefit $\Delta$ among the units. To design the method, we propose and advocate an underlying
equal profitability

equal profitability

named Peak Load Allocation Market (PLAM). We also formally define the problem, and describe the market resolution and the different conditions in which the added $\Delta$ benefit is distributed fairly according to different units' contributions. In the fourth section, We along with some initial experimentation. Finally, we briefly discuss our conclusions.
of benefit $B$.

, the benefit

More formally, we define Power Allocation Setting (PAS) as a tuple:

$$\langle \quad \rangle$$

• \{ ... \}
from the market. We now formally define the

\[ \epsilon \rightarrow \] is the benefit for unit

\[ \epsilon \rightarrow \] \( \epsilon \)

\[ ( \quad ) \]

it will be on, i.e., (1) or off, i.e., (0).

\[ \{ \cdots \} \]

\[ \{ \cdots \} \], we define the following:
• ServiceBenefit[ ] is the service benefit achieved by unit

• TotalBenefit[ ] = ServiceBenefit[ ] − is the total benefit achieved by unit ∈

• TotalBenefit = TotalBenefit[u] is the total organizational benefit achieved by all

We now define a number of desirable properties of the Peak Load Allocation Market.
\[
\{ \cdots \} \\
\forall \in \) TotalBenefit \geq TotalBenefit[ \\
\exists \in \) TotalBenefit \leq TotalBenefit[
\]

where TotalBenefit \] is the total benefit under SPA
Payment Allocation can increase the the benefit of a unit without reducing the benefit of

\[
\{ \cdots \} \\
\{ \cdots \}
\]

We say that Peak Load Allocation Market satisfies the Nash Equilibrium property if for

\[
\{ \cdots \} \\
\{ \cdots \} \text{ such that no unit can get a higher total benefit by quitting the coalition.}
\]

\[
\in \\
\text{StandAloneBenefit[} \leq \text{TotalBenefit[}
\]

where StandAloneBenefit[ ] is the maximum benefit that can be achieved by unit

\[
\text{StandAloneBenefit[} \\
\leq
\]

that satisfies the previously mentioned properties, as well as, the property of defined.

3.3 Optimizing Global Benefit

Here we will be using a service configuration function

\[ \to \{ \} \]

\[ \in \], whether it will be on (1) or off (0). To implement

\[ \{ \cdots \} \]

a service configuration ON

the service configuration value \[ \subseteq \] is defined as the total benefit

\text{ServiceBenefit|}
ServiceBenefit[

, we say that a service configuration ON is

\[ \leq \]

service configurations ON,

\[ \leq \]

\{ \in | \exists \in \in \}

An optimal ON configuration is a solution to

\{ \cdots \}

collaboration benefit \( \Delta \) is as follows:

\[ \Delta = - \{ \} \]
oration benefit $\Delta$ among the consortium’s participants. We propose a equal profitability of benefit $\Delta$, we decide on its distribution $\Delta \cdot \cdots \Delta$

\[ \forall \in \Rightarrow \Delta \geq \Delta = \Delta \]

distribute the collaboration benefit $\Delta$. Given a distribution $\Delta \cdot \cdots \Delta$ of $\Delta$, the Peak Demand Allocation Market resolution gives the figuration ON be the result of the Service Value optimization discussed in Section 2. Then:

\[ \in \{ \cdots \} \]

\[ \rightarrow \{ \} \]

is defined by ON \[ \forall \in \]

, note that the collaboration benefit increase $\Delta$

\[ \Delta = \text{ServiceBenefitIncrease}[ - \]

\[ \text{ServiceBenefitIncrease}[ - \{ \} - \Delta \]
distribution $\Delta \cdots \Delta$ of the Total Benefit $\Delta$. We propose

*equal profitability*

Given a distribution $\Delta \cdots \Delta$ of $\Delta$, we define the profit of unit

$$\text{Profit} = \gamma \begin{array}{c} \Delta \\
\{ \} 
\end{array}$$

Equal profitability means

$$\text{Profit}[1] = \text{Profit}[2] = \cdots = \text{Profit}[\Delta]$$

$$\begin{array}{c} \Delta \\
\{ \} \end{array} \cdots \begin{array}{c} \Delta \\
\{ \} \end{array}$$

$\Delta \cdot \{ \} \cdots \Delta \cdot \{ \}$

Because $\Delta \cdots + \Delta = \Delta$,

$$\left( \begin{array}{c} \{ \} \\
\{ \} \end{array} \cdots \begin{array}{c} \{ \} \\
\{ \} \end{array} \right) = \Delta$$

$$\begin{array}{c} \Delta \\
\{ \} \cdots \{ \} \end{array}$$

Finally, $\Delta \cdots \Delta$

$$\Delta \cdot \Delta \cdots \Delta \cdot \Delta$$
(API). The execution flow of the program is shown in the flowchart depicted in Figure 3.3.

unit, we calculate the base benefit bound by each unit’s individual peak demand budget and add all units’ base benefits together to determine the overall base benefit. After that, we compute the overall optimal peak demand distribution and determine the overall benefit and each optimal unit’s power allocation. The $\Delta$ benefit can be easily computed as the difference between the total optimal individual unit’s benefits bound by their respective peak demand budget and the overall optimal benefit of all unit combined. Finally, we determine each unit’s contribution to the $\Delta$ and distribute payments accordingly.

units and services with varying peak-demand budgets, benefits and service power needs.
The first data set consists of ten units and each unit contains six services. The second, third, and fourth, sets consist of a hundred, five hundred, and a thousand units respectively while each unit contained ten services. We assume that the benefit of running each service is consistent by normalizing that benefit into monetary value. Sample unit’s data are shown
tion is presented in Figure 3.4. As can be seen from the figure, some units had to give up some of their peak-demand budget to other units that presented higher benefit demand for assigned to other units. The total budget is allocated such that the highest benefit yielding
After both individual and the overall benefits are determined. We compute each unit

\[\text{equal profitability}\] principle described in Section 4. Since the \(\Delta\) gain in this set was (20.0), the corresponding \(\Delta\) distribution for each unit is captured in Table 3.3.

After the \(\Delta\) distribution is derived, each unit’s payment can be easily calculated using

\[\text{iteration variables were boolean (see Table 3.5). In addition, we noticed that }\Delta\text{ benefit increased}\]
<table>
<thead>
<tr>
<th>Unit</th>
<th>Δ Share</th>
</tr>
</thead>
</table>

The tests were performed on a moderate specification workstation (2.0 GHz dual core)
Table 3.5: Test Data Showing $\Delta$ Benefit Obtained and Optimization Time

<table>
<thead>
<tr>
<th># Units</th>
<th># Services</th>
<th>$\Delta$ Benefit</th>
<th>Optimization Time (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

service and payment allocation. Moreover, we formally defined the market and constructed an optimization model that satisfies desirable properties, i.e.,

*equal profitability*

resulted in an increase in the overall benefit of an organization based on the generated test

Our approach is designed for organization where operation of different units is greatly scheduling optimization to achieve the global benefit may work better.
decision optimization, and guarantees the formally defined properties of equilibrium and benefit distribution fairness.

benefits of such a decision.

peak-demand (kW) that an organization reaches during a specific contractual consumption period. This peak-demand constitutes a significant part of the electric power consumption
electricity to increase significantly. Therefore, C&I customers are motivated to reduce their economies of scales may not be realized. It could also be more beneficial to individual units their benefit by increasing their overall utility and reducing their cost.

university usually comprises of different units (e.g. schools, departments, centers, etc.). specifies its terms. More specifically, it states the price per kWh of consumption and an

shut down is made. Moreover, the units benefiting from the services are rarely consulted to
demand bound, but effectively it will paying for a peak-demand that it rarely reaches. On collective peak-demand budget, in lieu of monetary benefit, which also results in the total value (of services plus an extra benefit). The idea is that the exchange of the peak demand collaboratively selecting the peak demand limit, and (3) how to fairly distribute $\Delta$ among organizational units. More specifically, the contributions of this paper are as follows:

First, we propose and formally define a Peak-Load Demand Market framework. The represents the right which a unit has to consume up to the specified power bound. Each service and the power requirements over a fixed time horizon, e.g., one year. The market that each unit needs to make. We also define a set of desirable properties of the peak equilibrium and the benefit distribution fairness defined formally in the paper.

organization benefit while ensuring feasibility, i.e., that the total power consumption for
as well as the property of fair benefit distribution, defined formally in the paper.

named Peak-Load Demand Market. We also formally define the problem, and describe

the market resolution and a methodology in which the added $\Delta$ benefit of collaboration
is distributed fairly proportional to different units' contributions. In the fifth section, we

Finally, we briefly discuss our conclusions and results.
Every one of these services also has measurable amount of utility or benefit

More formally, we define a Power Allocation Setting (  

\[ \epsilon \]  

\[ ( \quad ) \]  

- \{ \cdots \}  
- \rightarrow  
- \forall \quad / \quad \rightarrow \quad \cap \quad \emptyset 
- \rightarrow  

\[ \epsilon \]  

\[ ( \quad ) \]  

\[ \epsilon \]  

- \times \rightarrow  

\[ \epsilon \]  

\[ \epsilon \]
\[ \times \rightarrow \in \quad \text{benefit received from running service} \quad \in \]

\[ \in \]

\[ \{ \} \]

\[ \in \quad \in \]

\[ \{ \} \quad \in \quad \text{is defined by:} \]

\[ \forall \in \quad \leq \]

The total benefit for \( i \), is defined as its optimal value minus its cost, i.e.,

\[ \quad \]

that total power at every time interval is less than the peak demand bound is satisfied.
in Figure 4.1. We now define a number of desirable properties of the Peak-Load Demand

\[
\begin{align*}
\{ \cdots \} & \quad \{ \cdots \} \\
\{ \cdots \} & \\
\forall \in & 
\end{align*}
\]
\[ \exists \epsilon \]

is the total benefit under

can increase the benefit of a single unit without reducing the benefit of other units. Similarly,

\[ \{ \cdots \} \quad \text{and} \quad \{ \cdots \} \]

We say that Peak-Load Demand Market satisfies the

\[ \{ \cdots \} \]

\[ \{ \cdots \} \] such that no unit can get a higher total benefit by quitting the coalition.

\[ \epsilon \]

is the maximum benefit that can be achieved by unit

\[ - \]

\[ \forall \epsilon \quad \leq \]

Here we use a service configuration function
\[ x \to \{ \quad \} \]

\[ \in \quad \in \]

1) or off (i.e.,

- \[ \langle \quad \rangle \]

- \[ \{ \quad \} \]

- 

- a service configuration

The service configuration value \( \) is defined as the total utility achieved by

\[ \{ \quad \} \]
\[
\forall \in \quad \in \quad \times
\]

\[
\forall \in \quad \forall \in \quad \leq
\]

} is defined as the maximum value among all feasible service configurations

\[
\times
\]

\[
\forall \in \quad \forall \in \quad \leq
\]

We say that a service configuration function \( \in \)

this modular representation, we can derive the optimal benefit value for any subset

\[
\{ \quad \}
\]
The optimization problem for finding
\[ \varepsilon \]

Thus, the benefit achieved by the collaboration is the total value of the optimal solution

\[ \varepsilon \]

\[ \{ \} \]

\[ \varepsilon \]

Therefore, the benefit

\[ \varepsilon \]

Therefore, if the units do not collaborate, their combined benefit
individual benefits, i.e.,

Note that the collaborative benefit
the non-collaborative benefit

\[ \geq \]

The difference

\[ \Delta = - \]

is the collaboration added benefit. We now need to
benefit \( \Delta \) among participating units into \((\Delta \ \ \Delta)\), where \( \Delta \geq \in \)

We say that \((\Delta \ \ \Delta)\) is a fair distribution of collaboration benefit of \( \Delta \) if, for each
\( \in \), all units make equal profit margin on their non-collaborative benefit, i.e.

\[ \Delta = \Delta \]

\[ \forall \in \Delta \Delta \]

To achieve this fair distribution \((\Delta \ \ \Delta)\)

\[ \Delta \ \ \Delta \]

*Equal Profit Margin*

\[ \forall \in ) \Delta \]

.
\[ \Delta = \Delta \]

\[ \Delta \]

\[ \forall \in \) \Delta \]

To resolve the market, we need to find the peak demand allocation \[ (\in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \in \i
maximum of the consortium benefit.

\[ \Delta, \text{ and thus } \Delta \geq \quad \in \quad \text{Equal Profit Margin} \]
suming all units are working collaboratively. The resulting allocation specifies which services

\[\begin{array}{c|c|c}
\hline
& \Delta \\
\hline
\end{array} \]

The benefits of working collaboratively versus working individually are compared. Then, the resulting added benefit (\(\Delta\)) is calculated. Using the *Equal Profit Margin* resolution of peak-load demand market section, the added benefit is distributed fairly among

Table 4.4: Added Benefit Distribution

\[\begin{array}{c|c}
\hline
& \Delta \\
\hline
\end{array} \]

Finally, the cost for each unit is calculated by determining the benefit to each unit and finding out the cost that each unit has to make part of the market resolution. A sample of
were performed. Since the market is run less frequently for specific peak demand contractual significance. As can be seen from the table, the largest test set of 1,000 units and 10,000
allocation as well as the cost. We formally defined the market and constructed an optimization model that satisfies desirable properties, i.e.,

*Equal Profit Margin*

the overall benefit of participating organizations and reduced their cost based on randomly
as well as the resulting payment by market participants. We also define four properties

*equal collaboration profitability*

algorithm, based on a formal optimization model and prove that it satisfies the desirable
To better understand interaction and collaboration between different units, consider

engine generators, etc.) at its disposal. With so many alternatives, finding the optimal

In order to model such a scenario, we must define how electrical power components (i.e.,

eration. While power components' internal workings can be unique, we try to find common
Making decisions in an environment where the benefit received from the operation components so that they achieve a better financial and operational level.

attributes. More specifically, the contributions of this chapter are as follows:

First, we propose and formally define a collaborative market framework. The basic value of running services at different levels of operation over a time horizon represented
has to pay or receive at every time interval when the market executes. We also define four

*equal collaboration profitability*

guarantees the satisfaction of the defined properties of market, namely,

*equal collaboration profitability*

defined formally in the next sections.
where we formally define the power market setting, market bids, market resolution and the resolution algorithm and how the extra benefit that resulted from the collaboration is fairly distributed among the participants. Finally, we briefly discuss our conclusions.

in lieu of shutting that service off. Unit 1 also has two types of power resources. Each first resource of unit 1 is a is a utility contract with a power company. This is not a power

Using a power resource typically incurs certain cost which can be either variable, fixed status indicators (e.g., charge level, efficiency, etc.) which vary depending on the type of consuming and producing components allow for control that affect their operation.
which could affect the entire contractual period. It can also arbitrarily curtail demand without giving much thought to the lost intrinsic value of the service being turned off. Unit

In this section we define the power market setting, market bids, and the market resolution
\[ \leq \leq \leq \leq \]

. A vector of controls \(- \cdots \leq \leq \leq - \cdots \)

\[ \{ \cdots \} \in \{ \cdots \} \]

\{ \cdots \}, and so on and finally unit \{ - \cdots \}

\{ - \cdots \}
the first column of matrix
\[ \{ \text{\(\exists\)} \mid - \leq \leq \} \]

\[
\langle \text{\(\exists\)} \rangle
\]

- \quad \rightarrow

associated with actions \(\sim\)

- \quad \rightarrow

associated with control actions \(\sim\)

\[ (\text{in dollars}) \text{ given control actions} \sim \]

- \quad \rightarrow

produces (or consumes) given the control actions \(\sim\)
The constraints that affect the power given or received from a battery resource given control actions

which is defined by

is defined as

Definition.

\[
\left\{ \{ * \} \mid \leq \leq \right\}
\]

\[
\leq \leq
\]

*


- 

- 

- 

- 

- 

- Equal collaboration profitability

Definition. \[ \{ (\quad) \mid \leq \leq \} \]

\[ \leq \leq \]

- 

- 

- 

- 

- 

- 

In the definition, note that the control actions for time interval 1 are exactly those of $$ * $ \leq \leq $$ satisfies its constraints $$ \cdots $$
To define the properties of \( \_ \), we need to define

**Definition.**

\[ \forall \_ \leq \leq (\neg \land \land) \]

\[ \forall \leq \leq \_ \]

\[ \in \]

\[ \forall \_ \leq \leq (\neg \land \land) \]

\[ \forall \leq \leq \_ \]

\[ * \]
Definition.

\[ \forall \quad \leq \leq ( \quad \neg \quad \wedge \quad * \quad ) \wedge \]

\[ * \quad \wedge \]

\[ \quad \quad \]

\[ \forall \quad \leq \leq \quad \]

\[ \]

\[ \]

\[ * \quad * \]

\[ \epsilon \]

\[ \forall \quad \leq \leq ( \quad \neg \quad \wedge \]

\[ * \quad ) \wedge \]

\[ \quad \quad \]

\[ \]

\[ \quad \quad \]

\[ \forall \quad \leq \leq \quad \]

\[ \]
increase the value of a unit without decreasing the value of another unit. More specifically,

\[ \{ \{ * \} | \leq \leq \} \]

\[ \{ \{ \} | \leq \leq \} \]

\[ \forall \in \geq \]

\[ \exists \in \geq \]

**Definition.** *Nash equilibrium:* We say that a market resolution satisfies the Nash equilib-

\[ \geq \]

**Definition.** *Equal collaboration profitability of market resolution (fairness):* We say that a market resolution satisfies the equal collaboration profitability property if every unit the same profit margin \( \text{, defined as} \)

\[ \text{reflects the total value that unit} \]

**Definition.** A market satisfies the properties of (1) Feasibility, (2) Pareto-optimality, (3) Nash equilibrium, and (4) Equal collaboration profitability, if for every market setting and market bids, it returns a market resolution that satisfies the corresponding properties.
After we have formally defined the market resolution and its desired properties, we now present how our market resolution algorithm works. We first define the global optimization

* time intervals to find their collaborative value and then compare it to their non-collaborative value and calculate the added benefit of collaboration ($\Delta$). Finally, we define how this added benefit is distributed in order to determine the payment (}

$$\forall \leq \leq \quad (\neg \land$$

$$\forall \leq \leq$$
on at the first time interval, we are only interested in the upcoming time interval.
5.4.2 Added Collaboration Benefit ($\Delta$)

\[ \Delta = \quad - \]

has a non-negative share of this $\Delta$, i.e.,

\[ \Delta = \Delta \lor \cdots \quad \Delta \geq \]

Value difference is the value that each unit

\[ \Delta \quad - \]
5.4.3 Added Benefit Distribution

The only remaining part is to find a method to calculate $\Delta$ our defined principle of equal collaboration profitability

\[ \Delta \quad \ldots \quad \Delta \]

equal collaboration profitability

\[ \forall \in \quad \Delta \quad . \]

\[ \Delta = \quad \Delta \]

\[ \Delta = \quad . \]

\[ \Delta = \quad . \]

\[ \Delta \]
\[ \{( \ast ) | \leq \leq \} \]

\[ \emptyset \hspace{1cm} \emptyset \hspace{1cm} \emptyset \hspace{1cm} \emptyset \]

Let \( \Delta = \emptyset \)

\[ \emptyset \hspace{1cm} \emptyset \hspace{1cm} \Delta \hspace{1cm} \emptyset \]

\[ \leftarrow \hspace{1cm} \leftarrow \]

\[ \leftarrow \]

\[ \Delta \leftarrow \hspace{1cm} \leftarrow \]

\[ \leftarrow \hspace{1cm} \Delta \]

\[ \Delta \leftarrow \hspace{1cm} \times \leftarrow \hspace{1cm} - \Delta \]

- Equal collaboration profitability
follows from the fact that $\Delta \geq 0$, and thus $\Delta \geq \epsilon$

collaboration profitability

and thus $\Delta$

□

This up to our knowledge is the first attempt to model a generic electric power collabo-

we formally model commonly used power components which has been briefly discussed in
In the previous chapter, we presented a general market framework. Defined in the market framework were market setting, market bids, and market resolution. More specifically, the bids included the definitions of the functions of cost, revenue, intrinsic value, and power.

Specific classes of resources and the actions that units may take depending on the type of section, a mapping between the general framework and specific types of commonly used
only two possible ways in which power flows. kw|

receiving power. It also can be equal to zero which indicates an idle and a turned off power

specific billing period, and the peak demand charge which measure the maximum rate of

$\in$

- $\ldots$
fore they are considered inefficient and need to be replaced by new battery storage
Renewable resources typically do not receive control actions except for emergency shut off.
Backup power generators differs from other power resources in terms of cost and availability.

efficiency function of fuel consumption depending the amount of power drawn from these back-up power resources. This function can be usually defined as piece-wise linear function

\[ \text{genEff} \rightarrow \ldots \in \{ \text{"turnOff"} \} \in \]

* times the efficiency times the fuel cost, i.e., genTotalFuelCost

\[ \times \times \times \times \]
Units typically can decide to turn on or turn off a power consuming service, i.e.,

\[
(\neg \forall \leq)
\]

other controls besides turning on or off a service, we consider these as discrete parts of the
mapping to the extensible framework. The modeling included the definition of the action
the implemented system is feasible and is able to operate efficiently within required time

mization can be achieved. We also formally defined a number of power components bids.

they achieve a better financial and operational level.

specifically, the contributions of this chapter are as follows:
services at different levels of operation over a time horizon represented as a bid that each
We first describe the general components variables and parameters. Then, we describe the implementation details of five power components:
maximum capacity, generator efficiency function, new generator cost, generator's annual
There is the fixed cost of acquiring a generator. In addition, there is the cost of fuel given the amount of power being drawn multiplied the efficiency factor for the specific capacity of the back-up generator. It also sets the flag of whether the generator is used at
that battery contain at before the first time interval starts. The battery also has other
charge/discharge specification rates. It also sets the current battery charge for the first
The terms usually specify the price per kW of consumption and the cost of the maximum
(i.e., fixed cost, maintenance cost). The renewable resource’s only operational constraint
indicates the monetary payment that a unit is willing to take in lieu of turning off that
generated following a typical daily consumption profile as depicted in Figure 7.4. This is a
typical profile for residential and office consumption pattern. Figure 7.5 provides a sample
of the value differences that each unit get under the different optimization models (i.e.,
global value does not reflect the market resolution and does not include the payment. The
market time constraints, two testing cases were constructed. The first test case involved randomly generated loads that conforms to a typical day load profile for residential and office setting with a probability distribution functions that introduces variation within that profile. This typical daily load profile hand a peak and an off-peak periods. The off-peak set sizes ranging from the lowest configuration with 10 units and a 100 components up to 1000 units and 10000 components where each test configuration has a sample size of 10 variables. The same size configuration was used to generate completely random data that didn’t conform to the daily consumption profile to measure the efficiency of the branch and
periods. The experiment results are captured in Table 7.1 for the typical daily profile and in Table 7.2 for the random daily profile. Depicted in Figure 7.8, the mean resolution time of the typical daily profile versus the random load are compared. Both showed very close

Figure 7.8: Simulation Mean Time - Typical Load Profile vs. Random Load
framework to efficiently operate at the specified time intervals with minimal overhead cost.
<table>
<thead>
<tr>
<th># of Units / # of Components</th>
<th>Mean Time (in Seconds)</th>
<th>Standard Error</th>
<th>Median</th>
<th>Standard Deviation</th>
<th>Sample Variance</th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
<th>Confidence Level (95.0%)</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
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<tbody>
<tr>
<td>10 / 100</td>
<td>0.81</td>
<td>0.04</td>
<td>0.74</td>
<td>0.12</td>
<td>0.01</td>
<td>0.30</td>
<td>0.69</td>
<td>0.99</td>
<td>0.08</td>
<td>0.72</td>
<td>0.89</td>
</tr>
<tr>
<td>50 / 500</td>
<td>3.93</td>
<td>0.12</td>
<td>3.82</td>
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<td>1.08</td>
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<td>4.20</td>
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<td>8.95</td>
<td>0.36</td>
<td>0.13</td>
<td>1.14</td>
<td>8.42</td>
<td>9.56</td>
<td>0.26</td>
<td>8.71</td>
<td>9.22</td>
</tr>
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<td>17.94</td>
<td>0.11</td>
<td>18.09</td>
<td>0.36</td>
<td>0.13</td>
<td>1.08</td>
<td>17.32</td>
<td>18.40</td>
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<td>Standard Deviation</td>
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<td>164.95</td>
<td>1.69</td>
<td>157.66</td>
<td>161.03</td>
</tr>
</tbody>
</table>
work for C&I organizations to collaborate on their power needs and resources. We first
resources in real-time. We defined the market setting, participant’s bids, a market res-
real-time. We also, defined the market resolution, execution intervals, schedule of resources

After that, an extensible decision guided framework was proposed to address different

ticipants’ bids, and a market resolution. We also defined the market properties the must
satisfied and proposed a market resolution algorithm that guarantees these properties.
data sets sizes and simulated power demand using a typical daily consumption profile and
straints proposed and produced a significant coalition gains as opposed to C&I participants.

- A more efficient and fair value distribution that takes into consideration the complexity

- be further studied to determine if manipulating the market bids has an effect on the outcome of the market resolution or it can unfairly benefit colluding parties.

- of an efficient communication with a very large pool of participant, and a central
sleer, “Distributed generation: definition, benefits and issues.”
X. Guan, P. B. Luh, H. Yan, and J. A. Amalfi, “An optimization-based

With Significant Wind Penetration,”
Artificial Intelligence
19th national conference on Artificial intelligence