Public-Private Partnership (PPP) Financing Model for Micro-Grids

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Abstract- In this article, we develop a Public-Private Partnership (PPP) financing model for micro-grids in which public entity transfers responsibility and risk of designing, building, operating and maintaining (DBOM) of the project to the private sector while maintaining the project ownership. The private sector owns the micro-grid’s revenue till the investment horizon; however, the revenue ownership will be transferred to the public entity after the investment horizon till a finite after-horizon period. Public entity incentivizes the private sector by providing an initial senior debt opportunity (through issuing zero coupon municipal bonds) and possibility of annual junior debts. Here, the (DBOM – PPP) financing model is merged with micro-grid short-term operation optimization into a single framework under host of short-term and long-term stochastic variables. An illustrative example is presented in which optimal financial activities and optimal micro-grid incremental portfolio over the course of investment horizon are defined for a vulnerable community located in 100-year flood zone region of city of Hoboken in New Jersey. From a practical point of view, the proposed model could have enormous impact on building a collaborative environment for public and private entities, which will facilitate implementation of micro-grid projects.

1. INTRODUCTION

Optimal operation of micro-grids in average normal conditions decreases the cost of supplying energy demands of the communities and has the potential to generate revenue. It is no secret that micro-grids can also increase the power resiliency of communities by continuous operation in stressed out conditions in which the power grid is disconnected due to extreme environmental conditions or technical issues. With this background, micro-grid projects
have gained popularity in long-term plans for “Sustainable and Resilient Communities”. A sustainable and resilient community by definition is a community, which is structurally developed to mitigate the economic and societal cost of disasters, and also have the capability to recover quickly [1]. Since the focus of many recent researches has been on the micro-grid’s design, implementation and operation, there is a lack in comprehensive models which solve the problem of financing such projects. Many of recent micro-grid projects have not been expanded from pilot scale to massive scale capable of supplying considerable portion of the communities’ power demands, due to existence of no clear financial plan that takes the project from the financing step out to the end of the micro-grid’s lifetime. In this paper, we are aiming to develop a long-term financing plan for incremental investment in community level micro-grids, which is based on the Public-Private Partnership (PPP) financing model. The (PPP) is a business relationship between a private sector entity and a government agency for the purpose of carrying out a project which will serve the public [2]. These contractual agreements are used to finance, build, operate and maintain large scale projects such as wastewater treatment plants, public transportation networks and convention centers. The advantages of such agreements are making the project a possibility in the first place and sooner completion of the project as well as transfer of risk from public entity to the private sector over the life of the project [3]. The (PPP) contracts come in a wide range of forms which are basically different in the degree of involvement of the private entity in the project. In this research, we take DBOM (Design- Build- Operate- Maintain) type of (PPP) models abbreviated as (DBOM-PPP) for micro-grid projects financing in which the private sector is responsible for design, build, operate and maintain the project over the course of a specified period, however public sector maintains the ownership of the project [4]. These project components are procured from the private entity in a single contract with financing secured by public sector. In all (PPP) contracts, public sector provides some incentives for the private sector such as loans proportionate to the level of risk the implementer bears, reduction in loan fees or/and transparent communication, collaboration and less political behavior [5]. We consider the public sector’s incentive in our model in the form of a “Senior debt” in initial year and possibility of annual “Junior debts” over the course of investment horizon [6]. The rest of the paper is organized as follows. In section (2), brief explanation of the developed model is presented. In section (3), the model is demonstrated through an illustrative example. Finally, conclusion is presented in section (4).

2. **Public-Private Partnership (PPP) Financing Model for Micro-Grids**

We will use the recent micro-grid’s operation and (DBOM–PPP) financing model as in [7]. In our (DBOM–PPP) model, the public sector provides a specified amount of fund for the private entity in the initial year of contract in the form of “Senior debt” through issuing sufficient number of zero coupon municipal bonds with face value $F$ and maturity at the investment horizon. In addition, public sector provides the private sector opportunity to borrow defined amount of funds in form of “Junior debts” with fixed rate of return in each year. “Junior debt” is either unsecured (i.e. do not require collateral behind the debts) or has a lower priority than of other debts claim on the same asset. It is worth noting that municipal bonds are tax exempted bonds issued by entities such as states, cities, counties, special-purpose districts or any other governmental entity under the state level, with the purpose of financing large scale infrastructural projects which could include micro-grid. Municipal bonds are categorized as (I)
General obligation bonds and (II) Revenue Bonds. In our model, we consider Revenue bonds in which the principal and interest rate are secured by the revenue from the project (i.e. micro-gird). Therefore, in order to build our long-term (DBOM –PPP) finance model, we need to accurately estimate annual savings/revenue from micro-grid operation under operation optimality condition. In our model, we merge the micro-grid short-term operation optimization and the (DBOM–PPP) financing model into a single framework under a host of short-term and long-term stochastic variables and solve it as a mixed integer stochastic optimization problem. The micro-grid’s operation optimization accounts for short-term savings, costs and penalties that are weighed according to the priorities of existing or planned residential and commercial sectors within the community in stressed out occasions. Hence, micro-grid saving is calculated in both average normal and stressed out conditions (i.e. power grid outage) with the objective of savings maximization. The power allocation between different sectors in case of stressed out conditions is based on criticality rank of each sector. The (DBOM –PPP) model is on the basis of cash flow reflecting the actual outflows and inflows of monetary values. The (DBOM –PPP) is formulated as a stochastic model for financial planning which defines the following:

I. Optimal annual average financial activities over the course of investment horizon.
II. Optimal annual micro-grid incremental portfolio under capacity constraints and available area limitation for micro-grid assets.

The objective of (DBOM –PPP) is to maximize the end of horizon cash flow plus the horizon time value of beyond the horizon cash flows till a finite beyond horizon period. We assume that the private entity can use the cash inflow resulting from micro-grid’s operational savings along with the senior debt and junior debts to purchase micro-grid assets. The private sector owns the micro-grid’s revenue till the investment horizon; however, the revenue ownership will be transferred to the public entity after the investment horizon till a finite after horizon period. The (DBOM –PPP) model captures the long-term market and price uncertainties such as natural gas price and capital cost of micro-grid assets. Taking Monte Carlo simulation approach, several sample path realizations over the course of project investment horizon are generated, and the deterministic (DBOM –PPP) is solved for each sample path and expected results are estimated.

3. ILLUSTRATIVE EXAMPLE

In this section, we are aiming to demonstrate how the (DBOM –PPP) model works for a community level micro-grid project through an illustrative example. We assume that micro-grid portfolio includes gas fired generators (GF), combined heat and power (CHP), photovoltaic cells (PV), electricity storage (ST), wind turbine (WT) and boiler. Therefore, we are considering this portfolio to supply as much as possible of electricity and heat demands of the community under study. We select the 100-year flood zone region (i.e. region with 0.01 probability of flooding in each year) in city of Hoboken, New Jersey, for micro-grid implementation. This specific region is selected according to the following reasons: (I) High vulnerability to extreme weather condition and power grid outage; as this region was extremely affected by super-storm Sandy in 2012, (II) Two super critical sectors (i.e. Health service and Information technology) are located in this region whose economic loss due to power outage are significant.
addition this region has high density of residential and retail units, which can be classified as medium critical sectors. Figure 1 shows the 100-year flood zone area in Hoboken along with land use classification in this region extracted using GIS (Geographic Information System) land use data.

![Figure 1: Land use classification in 100-year flood zone, Hoboken, NJ](image)

Table 1 shows approximate number of units and total roof area of each sector in the region. Roof area can be partially used for installation of PV panels.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of units</th>
<th>Total roof area (acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health service</td>
<td>10</td>
<td>11.38</td>
</tr>
<tr>
<td>Information technology (IT)</td>
<td>21</td>
<td>9.37</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>98.77</td>
</tr>
<tr>
<td>Leisure</td>
<td>8</td>
<td>28.69</td>
</tr>
<tr>
<td>Residential</td>
<td>1500</td>
<td>339.71</td>
</tr>
</tbody>
</table>
We also make the following assumptions regarding available area to install renewable power generation assets in our micro-grid portfolio:

- Half of the roof area of each sector can be used to install PV panels.
- WT installation is not practical in this region, since area under study is located in a dense municipal region with no available land to install massive wind turbine hardware.

Since we do not have access to hourly heat and electricity demand data for each of the units in this region, we use daily profiles for typical health service, information technology (IT), retail, leisure and residential sectors, as shown in Figure 2 [8, 9 and 10].

![Figure 2: Typical electricity demand profile for each sector](image-url)
We approximate the heat demand (supplied by gas fueled boiler and CHP) to electricity demand ratio for all sectors to be 0.4 [11]. We also assume that natural gas prices follow a Geometric Brownian Motion (GBM) with drift and volatility estimated using historical data (Henry Hub from 2000 to 2008) as demonstrated in Table 2.

Table 2: Parameters of natural gas price GBM process

<table>
<thead>
<tr>
<th>Natural gas initial price ($/mmBtu)</th>
<th>Drift</th>
<th>Volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.045</td>
<td>0.2</td>
</tr>
</tbody>
</table>

PV, ST and WT capital costs are assumed to be stochastic. We assume a decreasing trend and assign a binomial probability mass function to the rate (ψ) by which the capital cost decreases in each year. Table 2 demonstrates the parameters of assigned binomial probability mass functions.

Table 3: Parameters of Binomial distributions

<table>
<thead>
<tr>
<th>Asset</th>
<th>ψ₁</th>
<th>ψ₂</th>
<th>Probability (ψ₁)</th>
<th>Probability (ψ₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>0.8</td>
<td>0.6</td>
<td>0.33</td>
<td>0.67</td>
</tr>
<tr>
<td>WT</td>
<td>0.8</td>
<td>0.6</td>
<td>0.33</td>
<td>0.67</td>
</tr>
<tr>
<td>ST</td>
<td>0.8</td>
<td>0.6</td>
<td>0.33</td>
<td>0.67</td>
</tr>
</tbody>
</table>

GF, CHP and boiler investment costs are considered to be deterministic according to maturity of these technologies. Table 4 shows the annual investment cost of these assets over the course of investment horizon.

Table 4: Deterministic investment costs of GF, CHP and boiler over the course of investment horizon

<table>
<thead>
<tr>
<th></th>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF (S/MW)</td>
<td>100,000</td>
<td>100,100</td>
<td>100,200</td>
<td>100,300</td>
</tr>
<tr>
<td>CHP (S/MW)</td>
<td>1,200,000</td>
<td>1,210,000</td>
<td>1,220,000</td>
<td>1,230,000</td>
</tr>
<tr>
<td>Boiler ($/MW)</td>
<td>600</td>
<td>700</td>
<td>800</td>
<td>900</td>
</tr>
</tbody>
</table>

As stated earlier, we assume that the public entity provides a senior debt to the private sector via issuing sufficient number of municipal bonds (i.e. 500 in our case). In order to price zero-coupon floating rate municipal bond with maturity at investment horizon with face value \( F \), we use the binomial lattice method which is a popular approach to model one-factor Markov processes [12]. The binomial lattice weakly converges to Geometric Brownian Motion (GBM) stochastic process. In the binomial lattice, a binomial step of \( \Delta t \) is considered such that \( u \) and \( d \) are multipliers associated to up and down movements of variable in each step with risk neutral probabilities of \( p \) and \( 1 - p \) respectively. We start with constructing a binomial lattice structure for the floating short-term interest rate.
The risk neutral probabilities are set to 0.5, and each step’s up and down multipliers are set to be 1.25 and 0.9 respectively. Short term interest rate binomial lattice is demonstrated in Figure 3.

![Figure 3: Short term interest rate lattice](image)

Thereafter, we construct a binomial lattice for zero coupon municipal bond with terminal states’ values all equal to the bond’s face value. Working backwards on the binomial lattice and using risk neutral probabilities and floating interest rates, price of the zero coupon bond is calculated. Applying this methodology, we calculate the price of a municipal bond with maturity at year 3 and face value of $5,000 (i.e. common face value of municipal bonds) to be $4145.61 as demonstrated in Figure 4.

![Figure 4: Municipal bond pricing ($) lattice](image)
We assume that the annual junior debt is also limited to be no more than 2M$. We also assume that the public entity has a revenue stream from micro-grid operation for a finite after-horizon period (i.e. 15 years). Now, we proceed to the results of the devolved (DBOM –PPP) model. The average financial activities (i.e. annual junior debts, initial senior debt, annual cash from micro-grid savings spent to purchase micro-grid assets along with annual micro-grid savings) of the private sector in the context of (DBOM-PPP) model are presented in Figure 5.

The private sector is using the fund supplied by the public entity in the form of a senior debt along with the junior debts and cash inflows gained from micro-grid savings to install assets and maximize the cash flow position of both public and private entities in the investment horizon. The private sector cash flow position at the investment horizon includes the net cash flow at horizon. However, according to the fact that the public entity governs the project revenue right after the investment horizon, its cash flow position at the investment horizon includes beyond the horizon discounted cash inflows minus the issued municipal bonds principal payments to the bond holders (i.e. principal payment of 500 issued bonds with 5000$ face value). Table 5 presents the public and private entities cash flow position at the investment horizon.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Expected Cash flow position (M$) at the investment horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>28.78</td>
</tr>
<tr>
<td>Private</td>
<td>1.69</td>
</tr>
</tbody>
</table>

Results show how both public and private sectors can considerably benefit from a (PPP) financing model. We are also interested to define the optimal micro-grid incremental portfolio in each year. Figure 6, demonstrates the optimal micro-grid portfolio averaged over all scenarios.
The results show that investing on GF and CHP are most desirable among micro-grid electricity generator assets, which can be explained by low capital cost of GF and high efficiency of CHP in producing both heat and electricity. In addition, small investment on PV and no investment on ST can be justified by high capital cost of these assets. Investment in WT is not possible, according to spatial limitations. Boiler with very low capital cost is also in place to supply heat demands.

4. CONCLUSION

The model results clearly show how a Public-Private Partnership (PPP) model can be utilized to finance and implement a micro-grid project while both private and public entities’ profits are significant. The developed (DBOM-PPP) model guarantees a revenue stream for the public entity over the course of a finite horizon, while provides an opportunity for the private sector to apply its expertise and generate revenue for its own. Development of such a (PPP) model can be a forward step towards closer collaboration of public and private entities for more widespread micro-grid implementation.

5. ACKNOWLEDGMENT

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6. **REFERENCES**


6. The epec PPP Guide Website, Available Online: http://www.eib.org/epec/g2g/annex/1-project-finance/


