Y9.GEH2.2: System-level Cost-Benefit Analysis

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1. Project Goals

The objective of this task is to refine and enhance the cost benefit analysis (CBA) associated with a FREEDM System deployment case**.** This objective will be met by addressing the following sub-tasks:

i. Quantify and incorporate the costs associated with stranded assets as well as labor costs for removal of old equipment and installation of new equipment.
ii. Refine the marginal value of solar PV deployment, and ensure that assumptions regarding installation costs, operation and maintenance costs, and payments to customers via net energy metering or other tariffs are accounted for consistently.
iii. Incorporate non-FREEDM alternatives that can enable similarly high levels of solar PV deployment.
iv. Extend the sensitivity analysis to include Monte Carlo simulation of key uncertain parameters.

2. Role in Support of Strategic Plan

This Task is part of a cost-benefit analysis project, which is a cross-cutting activity.

3. Fundamental Research, Technological Barriers and Methodologies

The main challenge associated with this project is identifying the cos of alternative technologies as they may be at the early commercialization stage.

4. Achievements

4.1 Unreported Work – Cost-Benefit Analysis based on real utility circuits

In Year 8 report, the cost-benefit analysis results had been reported for the partial and full FREEDM deployment scenarios using the IEEE-34 circuit. This section summarizes the extension of the cost-benefit analysis for a more realistic case: partial FREEDM deployment on three actual circuits.

The first step of the analysis -performing detailed system simulations on these three circuits with partial FREEDM deployment and estimating the resulting system benefits- had been led by the other project team members. This work is reported in VII-GEH2.3. Table I from this study is given below, and it shows the estimate of the main benefits quantified under the "Feeder Benefits".

This team focused on economic assessment for each case by using the spreadsheet based tool that has been developed. Details of the method and the calculations involved are given in Y8 CBA report. Table 1 shows the detailed equipment costs (SST) for each circuit and the "System Benefits" which are the benefits accrued at transmission and generation level. The results, shown in the last two column of Tbl.1, indicate the estimated NPV (Net Present Value) and the payback period for each case. As these results indicate, FREEDM partial deployment for these circuits is economically very competitive. The NPV results presented in Year 8 were much lower than those presented in this paper, primarily due to the FIDs and the larger number of SSTs required for the IEEE-34 circuit (75 SSTs) compared to the real-world feeders considered in this case (32 SSTs).

Table 1: Benefits from Partial FREEDM deployment on three utility circuits

Circuit	Cost		System Benefits		Feeder Benefits		NPV	Discounted Payback Period
	SST	***Installation***	***Energy***	***Demand***	***Energy***	***Demand***		
Circuit A	$137,766	$35,680	$51,149	$105	$31,876	$7,675	$601k	3.2 yrs.
Circuit B	$41,268	$17,840	$41,598	$0	$28,830	$4,836	$599k	1.9 yrs.
Circuit C	$243,740	$64,670	$61,649	$831	$33,382	$7,840	$542k	4.7 yrs.

Figure 1 is a tornado diagram exploring the sensitivity of FREEDM partial deployment scenario for circuit A. The parameters listed were varied by +/- 25%, and the resultant change in NPV is displayed, with the most sensitive parameters at the top. The discount rate has the largest impact on SST NPV, followed closely by the value of solar and peak electricity price. Changes in the SST price do not significantly affect the NPV, likely due to the smaller number of SSTs installed in this case. Discount rate and price of SST are the only variables that reduce the NPV as they are increased, which is expected.

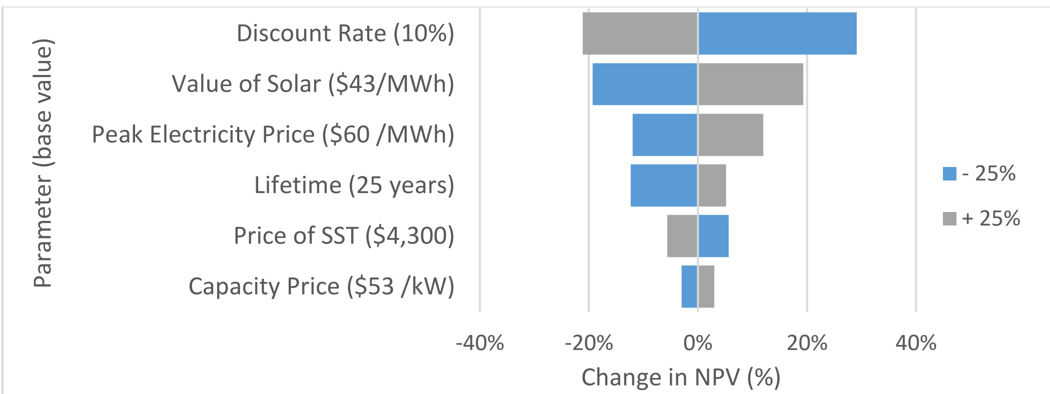

Figure 1: Sensitivity analysis of Year 8 Results – Duke Feeder A

4.2 Accomplishments in Y9

In Year 9, the cost-benefit analysis team focused on two tasks: (i) refinement of the CBA analysis to include additional costs to utilities (such as stranded investments and installation labor), and (b) conducting a comparative analysis between the FREEDM system and two main competing technologies. The whole project team worked collaboratively on identifying the alternative technologies.

Alternative Technologies

After a review of the commercially available options that offer solutions to high DER penetration issues, two alternatives were selected:

- In-Line Power Regulator (IPR) by Gridco Systems
- Smart Inverter by SMA Solar Technology AG (inverters owned by customers with DER).

These devices were selected because they offer solutions for grids with high DER, specifically regulating voltage, reducing reactive power, and offering smart communication options. A comparison of the technical characteristics of these devices is shown in Table 2.

Simulations on the three utility circuits with these alternative devices under the high DER penetration scenario have been conducted by the system benefit team. Benefits obtained from these studies are reported in VII-GEH2.3. Table 3 provides a summary of these results. In the table, “Energy savings – PV”

Table 2: Technical Comparison of FREEDM and selected alternatives

Company ***Product***	**Power Rating**	**Input Voltage Range**	**Output Voltage Range**	**Voltage Regulation Range**	**VAR Compensation Range**	**Efficiency**	**Price per Unit**
FREEDM ***SST***	0-100 kVA	3.6 kV V_{ac}	120V V_{ac} 200V V_{dc}	Any	Any	95%	$4,020
SMA ***Smart Inverter***	12 kW - 30 kW	Max 1000 V_{dc}	480/ 277 V_{ac}	244V-305V	0-1 (ind. or cap.)	98.5%	$4,150
Gridco Systems ***IPR-50***	50 kVA	240 V_{ac}	240 V_{ac}	± 10%	10% of Rating, Leading /Lagging	≥ 99%	$4,450

Table 3: System simulation results and unit costs of energy and demand

Summary	**Energy Savings - PV** ***(off-peak)*** ***(MWh)***	**Peak Reduction - PV** ***(kW)***	**Energy Savings - CVR** ***(peak)*** ***(MWh)***	**Peak Reduction - CVR** ***(kW)***
SST	1,187	2	534	146
Gridco	1,110	3	534	146
SMA	1,082	11	153	36
Unit Cost	**$43 / MWh**	**$52 / kW**	**$60 / MWh**	**$53 / kW**

is the incremental addition of DER beyond the server's base hosting capacity enabled by the technology. This value represents the value of additional solar above the circuit's maximum PV penetration. "Peak Reduction – PV" is the reduction in peak energy from incremental DER, and is negligible. "Energy Savings – CVR" is the reducing in peak energy consumption due to increased conservation voltage reduction allowed by each technology. The SMA is limited in its ability to provide additional CVR for technical reasons. "Peak Reduction – CVR" is the resultant drop in peak demand due to the more aggressive CVR allowed by each device.

Detailed Cost Estimate

The first challenge in CBA for alternative technologies considered involved estimating the cost for these technologies. Pricing for the SMA smart inverter was obtained through authorized distributors. Due to intellectual property issues, the exact price for the Gridco IPR could not be obtained. An estimate was made based on similar commercially available devices. Sensitivity to this cost estimate is explored in the results section. In addition to being installed alongside traditional distribution transformers as "grid add-on devices", each of these products requires an auxiliary component. The Gridco IPR requires a small inverter ($150), and the SMA smart inverter requires a DC disconnect ($408). The cost of these components is included in the analysis. Each grid upgrade technology is assumed to have the same useful lifetime of 25 years.

A full comparison of the FREEDM SST to competing devices must consider additional system costs from the perspective of the utility. For this analysis, cost estimates from industry partners directly involved with distribution grid maintenance[1] were used to calculate costs of stranded assets, scheduled transformer replacements, and installation costs. It should be noted that the two competing technologies are grid add-on devices, and do not replace the distribution transformer as the FREEDM SST does.

[1] Special thanks to industry partners: Booth & Associates, LLC; Pitt and Green Electric Membership Corporation; The Tarheel Electric Membership Association, Inc.

The stranded asset value represents the value utilities must write off when distribution transformers are removed from service and replaced with SSTs. Discussions with industry partners indicated that distribution transformers are depreciated on a 30-year schedule. However, they are routinely refurbished and reused in other feeders if they meet certain criteria (Barrow, 2016). Transformers can be refurbished for approximately 30-40% of the price of a new unit. Thus, installation of the FREEDM SST or any competing technology does not incur stranded asset costs to utilities, as in most cases these transformers can be reused in other feeders, reducing the need for new transformers. Industry partners also indicate that when a transformer is beyond repair, no salvage value is captured (Barrow, 2016). Any transformers removed during the installation of FREEDM that cannot be repaired have a salvage value of zero, and any that can be used elsewhere must simply be refurbished. Because it is not possible to guarantee that the utility will choose to refurbish all transformers replaced with SSTs, the refurbish cost is excluded from the analysis.

The FREEDM SST and Gridco IPR have similar installation costs – both are pole mounted (Vukojević, 2016) and the FREEDM SST design is approximately the same size as the Gridco IPR (Gridco, 2017). Replacement costs for a standard transformer are approximately $1,150, which includes labor, bucket truck usage, and replacement parts (excluding the transformer itself) (Barrow, 2016). This replacement cost is used as an estimate for the installation and maintenance costs for an SST and Gridco IPR. The installation cost of the SMA smart inverter is paid by the consumer, and is not included in this utility focused analysis.

Finally, we take into account the fact that standard distribution transformers have a 50-year life (Douglas, 2007; Barrow, 2016), and in a feeder with 300-450 transformers, it will be necessary to make some traditional transformer replacements over the 25-year life of the SST. In the Gridco and SMA case, because they do not replace transformers, there are 32 additional transformers in the feeder than in the partial SST deployment scenario. Each year, we estimate that $\frac{1}{50} = 2.0\%$ of these transformers will be replaced with a new transformer. Each of the non-SST alternatives incurs a $4,000 annual cost to account for the replacement of 2.0% of the distribution transformers that were not supplanted by an SST. Accurate estimates of annual maintenance costs of the FREEDM SST are not yet available, although it is expected that the more advanced SST will require more maintenance than traditional transformers. To model this expectation, parts and labor costs associated with transformer repair ($1,150) are imposed every 5 years on each SST and Gridco IPR device installed. The SMA smart inverter is a device that would be installed and maintained by customers with solar DER, so there is no maintenance cost borne by utilities.

In addition, due to the benefits gained by utilities when customers install the SMA smart inverters, a utility subsidy is assumed. Based on a review of utility subsidies for energy efficient appliances (NCCETC, 2017), this analysis assumes the utility will cover 25% of the cost of the SMA smart inverter.

Monetizing Energy Savings

In order to monetize benefits, the unit cost of energy and peak reduction used in monetizing benefits is calculated. The rates for peak reduction and energy costs were obtained by averaging costs over seven different utility companies in the northeastern U.S. (GSA Associates, 2012). Peak energy costs were found to be $60/MWh over all seven utilities. The capacity cost represents the value to utilities of a reduction in peak demand, realized through deferred capacity-related investments. This rate is $52/kW for off-peak demand reductions, and $53/kW for peak demand reductions.

The value of solar is the value to utilities for each additional MWh of solar power injected into the grid, and represents a combination of energy costs, loss reduction, deferred transmission and distribution upgrades, and deferred off-peak capacity investments. This value is derived through a study of "value of solar" studies (Mills & Wiser, 2012; Arizona Public Service, 2013; Energy and Environmental Economics, 2013), and the methodology is described in the FREEDM Year 8 report and pending publications (Sun et al, 2016). These costs are summarized in Table 3.

Cost-Benefit Analysis

Table 4 shows the final results of the cost benefit analysis for each technology, based on the stated assumptions concerning costs and benefits. The analysis utilizes a 10% discount rate (Sun et al, 2016) over a 25-year horizon. The savings of the SST and alternative technologies was based on the detailed simulation results summarized in Table 2. For the representative feeder analyzed, the FREEDM SST emerges as the most financially attractive option for first adopters.

Under these assumptions, utilities looking to accommodate high levels of DER penetration would find the largest net benefit in choosing the FREEDM SST, followed closely by the Gridco device. The smart inverter does not provide enough benefits to justify the installation cost, and it should be noted that in practice, the deployment of the smart inverter is dependent upon the DER prosumer's willingness to purchase with the given utility subsidy. The SST and IPR are the only devices fully within the utility's control to install. Were the utility to cover 100% of the smart inverter cost to ensure full deployment, the net present value of the SMA becomes negative over the 25-year time horizon.

Table 4: Comparison of financial metrics amongst competing technologies. Note: all figures in thousands of dollars.

Technology	Estimated Utility Investment Cost	Estimated Annual Benefits	Estimated Net Present Value	Discounted Payback Period
FREEDM SST	$175	$84	$601	3.2 years
Gridco IPR	$168	$76	$539	3.4 years
SMA Smart Inverter	$148	$54	$345	4.4 years

The analysis in Year 8 discussed the sensitivity of the cost-benefit results to parameter assumptions, such as discount rate and SST cost. In this Year 9 analysis, most assumptions made were applied to all three technologies; therefore, a sensitivity analysis of these results would show similar variations in NPV for all three options and would not provide much insight. However, it is useful to test the cost estimates to find the breakeven price. The breakeven price of alternate technologies is the per unit device cost that provides an NPV equal to the FREEDM SST.

The breakeven price of the Gridco IPR is $2,050, which is a 55% reduction in the cost estimate used. There is no breakeven price for the SMA smart inverter, indicating that even with full deployment and 0% utility subsidy, this device does not provide equal net benefits as the FREEDM SST. Alternatively, the breakeven price of the FREEDM SST which would provide the same benefits as the Gridco option is $6,700, a 56% increase in estimated cost. These breakeven prices indicate that the relative results are robust to variations in device cost. Under the described assumptions, partial deployment of the FREEDM SST is the most attractive option for utilities.

5. Other Relevant Work Being Conducted Within and Outside of the ERC

Utilities regularly undertake this type of cost-benefit analysis when making investment decisions. Regulated utilities, such as industry partner Duke Energy in the Carolinas, create Integrated Resource Plans, which discuss future investments, capacity expansion, and projected impact on rates (Duke Energy Progress, 2016). This framework can help these utilities evaluate grid upgrade options in a consistent manner.

6. Milestones and Deliverables

The main deliverable is the final report on the work performed.

7. Plans for Next Five Years

There are currently no plans to further expand this cost benefit analysis over the next five years.

8. Member Company Benefits

The framework and methodology for assessing the financial viability of grid upgrade devices presented in this work can be utilized by member companies who wish to investigate grid upgrades.

9. References

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